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An Analysis of Effect of Water Resources Constraint on Energy Production in Turkey

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December 2012

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AN ANALYSIS OF EFFECT OF WATER RESOURCES CONSTRAINT ON ENERGY PRODUCTION IN TURKEY

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Submitted in partial fulfillment of the requirements for the degree of

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ABSTRACT

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LIST OF ACRONYMS AND ABBREVIATIONS

Bgal/day	Billion gallons per day
BO	Build-Own-Operate
BOTAS	Petroleum Pipeline Corporation
BWR	Boiling Water Reactors
°C	Celsius
CCS	Carbon Capture and Sequestration
CER	Consortium on Energy Restructuring
CO_2	Carbon dioxide
CPV	Concentrating Photovoltaic
CSP	Concentrated solar power
DAP	Eastern Anatolia Project
DOE	Department of Energy
DSI	General Directorate of State Hydraulic
EGS	Engineered Geothermal Systems
EIA	U.S. Energy Information Administration
EJ	Exajoule
EMRA	Energy Market Regulatory Authority
ENTSO-E	European Network of Transmission System Operator for Electricity
EPA	Environmental Protection Agency
ETKB	Ministry of Energy and Natural Resources
EUAS	General Directorate of Electricity Generation Company
GAP	Southeastern Anatolia Project
GPD	Gallons Per Day

GW	Gigawatt
GWh	Gigawatt-Hour
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
ISPAT	Investment Support and Promotion Agency of Turkey
J(th)	Joules Thermal
KOP	Konya Plain Project
kWh	Kilowatt-Hour
MFA	Ministry of Foreign Affairs
MGD	Million Gallons per Day
MoEF	Ministry of Environment and Forestry
Mtoe	Million Tonnes of Oil Equivalent
MW	Megawatt
NGCC	Natural Gas Combined Cycle
NREL	National Renewable Energy Laboratory
OECD	Organization for Economic Co-operation and Development
OTEC	Ocean Thermal Energy Conversion
PV	Photovoltaic
PWR	Pressurized Water Reactor
REPA	Wind Energy Potential Atlas
STE	Solar Thermal Electricity
TEIAS	Turkish Electricity Transmission Corporation
TUIK	Turkish Statistic Institute
TOR	Transfer of Operation Rights
TWh	Terawatt-Hour

UNEP	United Nations Environmental Programme
U.S.	United States
USGS	United States Geological Survey
WBCSD	World Business Council for Sustainable Development

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Huseyin Karakas and Timur Tilki

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I. INTRODUCTION

A. OVERVIEW

Water is always required for humans and other life forms to sustain their lives. Because of that, water is extremely important. Hence, people have chosen to live near rivers and major water resources since the beginning of mankind. (Mesopotamia, known as the birthplace of civilization, was sited between two major rivers. These rivers are Euphrates and Tigris. The ancient society of the Egyptians was sited around the Nile.) Total demand for freshwater changes depending on urban growth, population growth, and global water use. Generally, water use can be divided into three categories: personal uses, irrigation, industrial uses. Industrialized and developing countries follow discrete patterns in water use. Total demand for water is gradually increasing because of the rapid increment in the world's population. There are three major reasons for this increment. These are industrialization, increased development, and growing affluence.

Water is significantly important for the energy industry. It is required in energy-resource extraction, refining and processing, and transportation. Water consists of important part of electricity generation. Considerable amount of water is required for fossil fuel and nuclear power plants and hydroelectric systems. Hydroelectric power plants use water directly. Water is needed to turn turbines for hydropower and is also used extensively in thermal power plants. Water is required to produce steam for thermoelectric power and also needed for cooling equipment by absorbing the waste heat produced by power generation.

The relationship between the use of water and the use of energy has become increasingly important in this changing world. The growing populations demand more water and energy supplies. Currently, electric power generation is major water withdrawal and use sectors in the world. Additionally, future energy development; such as biofuels, hydrogen, or synthetic fuels production; oil shale development, carbon sequestration, and nuclear power development can significantly augment water use and consumption. Future generations may be confronted with problems related to the utilization, development, and management of the critical resources of water and energy because of the current increment in energy use and water demand.

In the future, water and energy demand will continue to increase. Competition for the use of water between the energy, domestic, agricultural, and industrial sectors is rapidly increasing. This will affect the amount of energy production and electric power generation. Reliability and security of energy and water resources will be the other important issues in the future.

B. STATEMENT OF THE PROBLEM

Turkey, with a surface area of 302,535 sq miles (783,562 km²) and a population over 73 million, is a country with considerable water resources in a region where a sufficient amount of water has never been available. Water is expected to be the key to war and peace in the near future.

In Turkey, important attempts have been made in the second half of the 20th century to develop the country’s water resources. Rapid growth of population, plus an increase in the standard of living and accompanying industrialization, have raised the water demand considerably and are stressing the quantity and quality aspects of the country’s water resources. To meet this demand, Turkey has been constructing dams, hydropower plants, and irrigation projects throughout the country.

Currently, Turkey imports 70% of its energy need from neighboring countries. Along with the economic growth, Turkey’s energy demand is increasing. In other terms, Turkey’s dependency on its neighbors will augment. In order to diminish this dependency, Turkey should start to generate its own electricity using its own resources. On the other hand, Turkey’s water resources have been decreasing over decades. In this project, Turkey’s energy production capabilities, considering the water resources’ limitations, are analyzed. This thesis project also evaluates the maximum amount of energy production in Turkey using its diminishing water resources in an optimization model.

C. PURPOSE OF THE PROJECT

The purpose of this study is to measure the influence of Turkey's water resources on energy production considering growing demand in the future. In this study, water usage in electricity generation in different types of power plants is examined. This study will analyze the relationship between available water resources and growing future energy demand. The results of this study provide a model allowing decision makers to determine how to manage an effective water and energy policy for the next decades.

D. RESEARCH QUESTIONS

- Does Turkey have sufficient water resources to allocate for energy production in the future?
- How many power plants should Turkey build to meet its growing future energy demand?
- What is Turkey's capability of using renewable energy and what portion of the total energy demand will be satisfied by these renewable energy plants?
- What would be the most effective and efficient water resources' management policy that should be implemented by the Turkish Government?

E. ORGANIZATION OF THE PROJECT

This study starts with a literature review to explain the relationship between water resources and energy production. Then, the current types of power plants in Turkey, in terms of their electricity production capacity and water usage, is investigated. Afterwards, the amount of water resources and energy demand is estimated. Additionally, an optimization model is built and the results of this model are interpreted.

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II. BACKGROUND

A. WATER

1. Water Availability and Use

Water has been of vital importance for human beings since the earliest days of civilization. Water is essential for growing food; for household water uses, including drinking, cooking, and sanitation; for human health, industrial usage, energy production, transportation, and for supporting the earth's ecosystems (Gleick, 2009).

The consumption of renewable water resources has grown six-fold in the 20th century. Considering the estimation that world population will increase by another 40 to 50% within the next fifty years, the demand for water will increase substantially. This will have serious consequences on the environment (World Water Council, 2012).

The agricultural sector is the most dominant user of water, accounting for 70% of all water consumption worldwide, compared to 20% for industry, and 10% for domestic use. Agricultural water use is especially heavy in the developing world. For instance, some countries in Asia, Africa, and South America use more than 79% of their total freshwater supply for agricultural purposes. Irrigation constitutes the biggest portion in the agricultural water use. In the United States, 80% of agricultural water is used for irrigation (The Global Water Crisis: Our Inevitable Fate, n.d.).

In addition to irrigation, water is essential for domestic use (including drinking, cooking, bathing, and cleaning) and in the industrial sector. Growth in water consumption in these sectors is faster than the agricultural sector. Between 1950 and 1995, water withdrawals for domestic and industrial uses grew four-fold worldwide, compared with just over double for agricultural uses (Cosgrove & Rijsberman, 2000). Growing domestic and industrial water uses and the high cost of finding new water resources will adversely impact the availability of irrigation water that is needed to grow food. Besides, the cost of supplying water for household and industrial uses is also increasing rapidly, since investment to supply more water to growing cities must typically tap water at a greater distance from the city (Rosegrant, Ximing, & Sarah, 2002). In order to overcome these difficulties, scientists have developed several nontraditional technologies, such as desalination. There are two different techniques in the desalination process: one is the evaporative technique and the other is membrane desalination. While the former has proven too expensive for all but the richest, water-scarce countries, the latter offers significant cost advantages. Despite these advantages, however, desalination today contributes only about 0.2% of global water withdrawals and perhaps 1% of drinking water (Martindale & Gleick, 2001). Because of the high capital, energy, and transportation costs (pumping water inland), it is likely that this technology will remain concentrated in the coastal regions of developed water-scarce countries and island nations.

In addition to its value for direct human consumption, water is integrally linked to the provision and quality of ecosystem services. On the one hand, water is vital to the survival of ecosystems and the plants and animals that live in them; on the other, ecosystems regulate the quantity and quality of water. Wetlands retain water during high rainfall and release it during dry periods, purifying it of many contaminants. Forests reduce erosion and sedimentation of rivers and recharge groundwater (Bergkamp & Bos, 2001).

2. Water Scarcity and Conflict

Water use for humans is increasing because of the population growth and changes in lifestyle. On the other hand, variations in water availability will lead to scarcity in water to produce food for human consumption and industrial use of water. As the water resource becomes scarce, tensions among different users may intensify, both at the national and international levels. Worldwide, over 260 river basins are shared by two or more countries (Wolf, Natharius, Danielson, Ward, & Pender, 1999). If there is an absence of strong institutions and agreements between the countries, it can lead to trans-boundary tensions and conflict. The main reason for water crisis in the world stems from bad management of water resources. So, the decision makers should be aware that water resources are limited and need to be protected in terms of quantity and quality. With the proper approach to water management, countries can save huge amounts of water. For instance, even changes in food habits can cause water consumption. For example, growing 1kg of potatoes requires only 100 litres of water; whereas 1 kg of beef requires 13,000 litres (World Water Council, 2012).

In an interview with Deborah Zabarenko, Reuter's environment correspondent, Kirsty Jenkinson (Kirsty, 2011), director of the World Resource Institute, stated that "Water use has been growing at more than twice the rate of population increase in the last century and water use is predicted to increase by 50% between 2007 and 2025 in developing countries and 18% in developed ones, with much of the increased use in the poorest countries with more and more people moving from rural areas to cities.''

Since the demand for freshwater is increasing, especially in some regions that suffer from water shortage and climatic changes, water supply is uncertain. Water and water-supply systems are likely to be the objective of military action. The nations that do not have enough water supplies can consider access to water resources as part of national security. So, it is likely that competition and disputes over shared freshwater resources can occur between these nations. Besides, some nations that have enough water resources can use water and water-supply systems as instruments of war.

Insufficient water supplies in many countries, especially in the Middle East, causes water to be used at a rate faster than natural processes can replenish it. This leads to falling ground water levels, reliance on expensive desalination projects, and imports of water across borders. Since the global climatic changes will cause unpredictable changes in water supply, countries will become more vulnerable to water related conflicts. According to Gleick (2009):

> Water-related disputes are more likely to lead to political confrontations and negotiations than to violent conflict. But recent disturbing examples of water-related conflicts, the apparent willingness to use water-supply systems as targets and tools of war, and growing disparities among nations between water availability and demand make it urgent that we work to reduce the probability and consequences of water-related conflict. Hydrologists and water-resources specialists must begin to collect and more widely disseminate data on the supply and use of shared water resources, and on ways of reducing inefficient uses of water. International legal experts must better understand the links among natural resource needs, national sovereignty, and water rights. And academic and military scholars need to better understand the threats of conflict arising from a wide range of resource and environmental problems, and to hone the tools for preventing those conflicts (Gleick, 2009).

3. Water Facts and Statistics

In 60% of European cities with more than 100,000 people, groundwater is being used at a faster rate than it can be replenished (WBCSD, 2006).

By 2025, 1 800 million people will be living in countries or regions with absolute water scarcity, and two-thirds of the world population could be under stress conditions (FAO Water, 2012).

According to United Nations Environmental Programme (UNEP), "Global Environment Book (2003)," the total volume of water on Earth is about 1.4 billion km^3. The volume of freshwater resources is around 35 million km^3, or about 2.5% of the total volume. Of these freshwater resources, about 24 million km^3 or 70% is in the form of ice and permanent snow cover in mountainous regions, the Antarctic and Arctic regions as displayed in Figure 1.

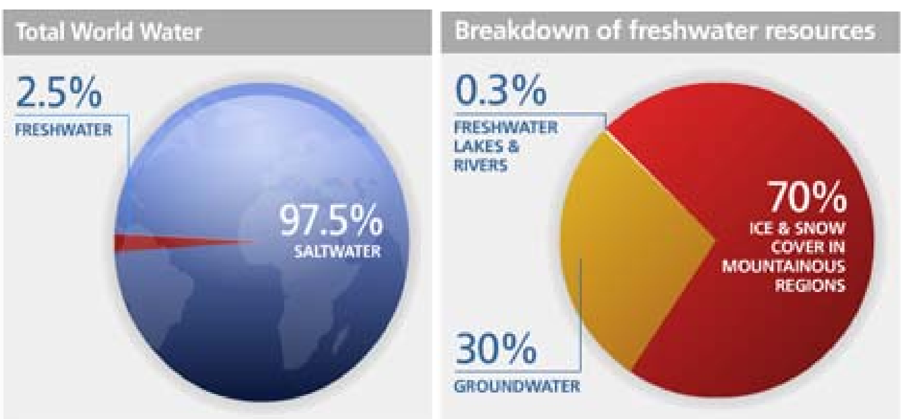

Figure 1. World Water Statistics (From UNEP, 2003).

Around 30% of the world's freshwater is stored underground in the form of groundwater, and this constitutes about 97% of all the freshwater that is potentially available for human use. Freshwater lakes and rivers contain an estimated 105,000 km^3 or around 0.3% of the world's freshwater.

The total usable freshwater supply for ecosystems and humans is about 200,000 km^3 of water—less than 1% of all freshwater resources (UNEP, 2003).

B. ENERGY

Energy is in every part of our lives. All life on earth depends in some way on energy. Most of the earth energy comes from the sun. It travels to the earth in rays or waves. Plants use energy in this form for its nourishment. The sun's energy is also stored in coal, wood, and oil which is also used to produce food and modify matter. People's need for energy is essential for survival, so the energy production and consumption are some of the most important activities of human life. Maria van der Hoeven, Executive Director of International Agency, stated that "Nobody can do without energy. The relationship between economic growth and the demand of energy is crucial, and the availability of energy sources to economies is crucial." Many essential activities, such as agriculture, computing, manufacturing, construction, and health and social services depend on access to energy. Energy is necessary for development of civilization.

Energy is known to exist in a variety of different forms. Among these are heat, light, chemical, electrical, solid, mechanical, and nuclear. As a general rule, energy can change from one form to another. For example, the steam driven turbine generator of a power plant is designed to convert heat energy into electrical energy; the heating system of a building converts the chemical energy of gas or fuel into a usable form of heat. Electrical energy may also be converted into light, heat, or mechanical energy through the use of different equipment.

Energy sources can be classified into two groups: nonrenewable and renewable. Most of the energy comes from nonrenewable energy sources, such as coal, petroleum, natural gas, and uranium. They are used to generate electricity, to heat our homes, and to manufacture all kinds of products. They are called nonrenewable because their supplies are limited.

Renewable energy sources include biomass, geothermal energy, ocean energy, hydropower, solar energy, and wind energy. They are called renewable energy sources because they are replenished in a short time. Renewable energy sources are used mainly for generating electricity (Renewable Energy Sources in the U.S., n.d.).

1. Energy Sources

a. Fossil Fuels

There are three major forms of fossil fuels: coal, oil, and natural gas. Fossil fuels remain the primary source for the production of electricity. The combustion of these fuels releases their chemical energy which produces heat to power steam turbines. The steam turbines power rotating electric generators which turns kinetic energy into electricity. Since the production of electricity from fossil fuels involves several energy conversion steps, there is always some loss in the energy conversion process. As combustion of fossil fuels also produces carbon monoxide, carbon dioxide, sulfur dioxide, and nitrous oxides gases, electricity generation from these fuels has negative impact on the environment and human health. These "greenhouse gases" contribute to acid rain and global warming effects (Consortium on Energy Restructuring, 2007).

According to the EIA statistics (2010), the world currently consumes 86.952 million barrels of crude oil daily. As displayed in Figure 2, the world has experienced growth in its consumption of oil for the majority of the years since the early 1980s. Oil has the highest share within global energy consumption. It will continue to grow because some developing countries, such as India and China (accounting for over a third of the world's population), substantially need crude oil to meet their energy demands (Hathaway, 2009).

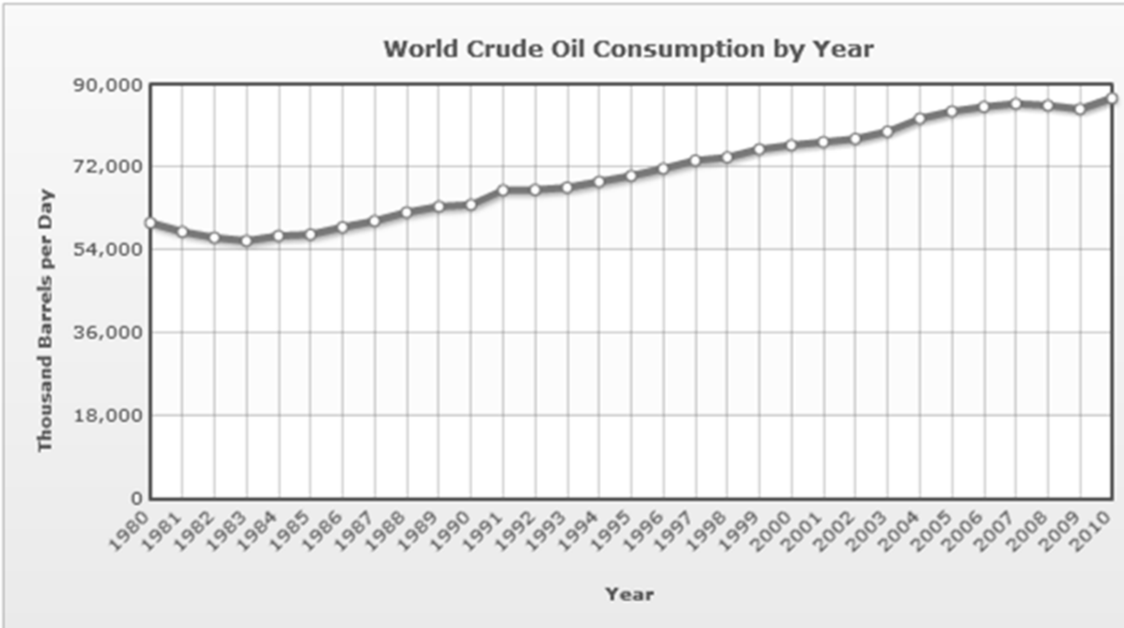

Figure 2. World Crude Oil Consumption by Year (From EIA, 2011).

Coal has been a useful resource throughout history. It is primarily used for the generation of electricity and/or heat. It is also used for industrial purposes. Coal is the largest source of energy for the generation of electricity. According to EIA statistics, world coal consumption was about 7.99 billion short tons in 2010. This is expected to increase to 9.98 billion short tons by 2030 (U.S. Energy Information Administration, 2011). As the world largest producers of coal, China produced 2.38 billion tons and India produced about 447.3 million tons in 2006. 68.7% of China's electricity comes from coal. The U.S. consumes about 14% of the world total, using 90% of it for generation of electricity (U.S. Energy Information Administration, 2011). Figure 3 shows hard coal production from 1971 to 2010 by region (International Energy Agency, 2011).

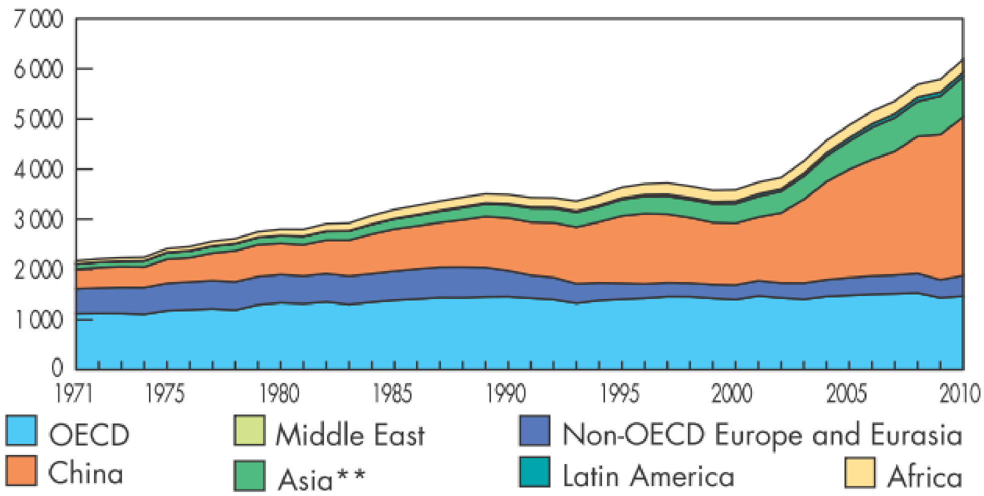

Figure 3. Global Hard Coal Production from 1971 to 2010 (From IEA, 2011).

Natural gas is mostly made up of methane. Methane is a simple chemical compound that is made up of carbon and hydrogen atoms. This gas is highly flammable. Natural gas is a fossil fuel formed when layers of buried plants and animals are exposed to intense heat and pressure over thousands of years. The energy that the plants and animals originally obtained from the sun is stored in the form of carbon in natural gas. Natural gas is combusted to generate electricity, enabling this stored energy to be transformed into usable power. Natural gas is a major source of electricity generation through the use of gas and steam turbines. According to International Energy Agency data (2011), the world use of gas reached 1266 Mtoe in 2009. Compared with 1971 data, that is a 93.87% increase in total consumption.

b. Nuclear Power

Nuclear energy is a finite energy source that uses an indirect conversion process to produce electricity. Nuclear power is generated using uranium. This metal is mined in various parts of the world. Uranium is a nonrenewable resource and it is extracted through traditional mining techniques or chemical leaching. Once mined, the uranium ore is sent to a processing plant to be concentrated into enriched fuel (i.e., uranium oxide pellets). Enriched fuel is then transported to the nuclear power plant (U.S. Environmental Protection Agency, n.d.).

The World Energy Outlook 2009 report from the OECD's International Energy Agency (IEA) shows that nuclear power produced around 11% of the world energy needs in 2009. It produces huge amounts of energy from small amounts of fuel without the pollution from burning fossil fuels (IEA, 2009). There are also some military ships and submarines that use nuclear energy for engine power.

There are two basic forms of nuclear energy: fission and fusion. Since the fusion reaction has never been controlled, only the fission reaction is used to produce electricity. Fission releases energy that can be used to make steam. This is used in a turbine to generate electricity. Nuclear fission produces much greater energy content than fossil fuels. Uranium contains an energy content of approximately 10^{10} Btu/kg or about one million times the energy content of fossil fuels (U.S. Environmental Protection Agency, n.d.).

As of December 2009, the total number of nuclear reactors in the world was 436 (Findlay, 2010). Because some large reactors have been shut down in Japan, annual generation of nuclear power has been on a slight downward trend since 2007, decreasing 1.8% in 2009. In 2009, nuclear power met 13–14% of the world's electricity demand (World Nuclear News, 2010). Figure 4 shows the world nuclear energy consumption by region between 1990 and 2030. According to projections, nuclear energy consumption will continue to grow, especially in some developing countries, such as China and India.

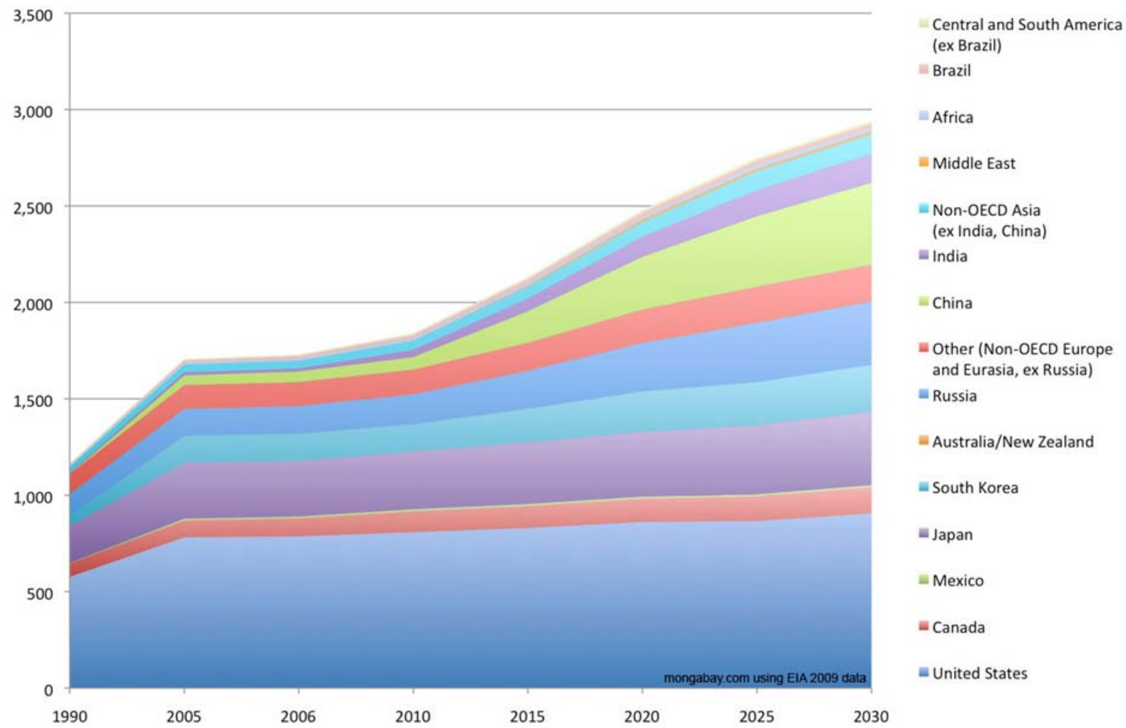

Figure 4. World Nuclear Energy Consumption from 1990 to 2030 (From EIA, 2009).

c. Hydropower

The definition of hydropower by the Consortium on Energy Restructuring (CER, 2007):

> Hydropower is the electrical energy derived from turbines being driven by flowing water in rivers, with or without man-made dams forming reservoirs. In a hydropower plant, the potential energy of a mass of water in a reservoir a distance above the stream bed is converted to kinetic energy by flowing through a hydraulic turbine. The resulting kinetic energy of the turbine drives an electric generator. Hydropower is available wherever a suitable site exists having enough stream flow, potential drop and area.

The most common type of hydroelectric power plant uses a dam on a river to store water in a reservoir. Water released from the reservoir flows through a turbine, spinning it. This in turn activates a generator to produce electricity.

Comparing hydropower with other energy resources, it has several advantages. The most remarkable feature of hydropower is that its storage capacity and fast response characteristics are valuable to meet sudden fluctuations in electricity demand (IEA, n.d.). Presently, hydropower is the world's largest source of renewable electricity.

d. Solar Energy

Solar energy technologies use the sun's energy and light to provide heat, light, hot water, electricity, and even cooling, for homes, businesses, and industry. Solar radiation, which is a renewable energy source, includes energy used directly as intercepted solar radiation or indirectly as wind and hydropower. Direct use of solar power includes active types involving photovoltaic cells and passive types using radiation to heat solar collectors. There are two main types of concentrating solar energy technologies: concentrating photovoltaic (CPV) and concentrating solar thermal electric power (CSP) (IEA, n.d.).

Concentrating photovoltaic cells convert sunlight directly to electricity. The best photovoltaic cells have efficiencies in the 14% to 17% range (International Renewable Energy Agency, 2012). Photovoltaic solar cells generate direct current. Thus, they require inversion equipment to obtain the desired alternating current for most large-scale operations.

Concentrating solar power systems focus sunlight with mirrors to create a high-intensity heat source. Then this heat is transformed first into mechanical energy (with turbines or other engines) and then into electricity—solar thermal electricity (STE).

Solar cells and the equipment needed to convert their direct-current output to alternating current for use in a house is expensive. Electricity generated by solar cells is still more than twice as expensive as electricity from fossil fuels. Part of the problem with cost is that solar cells can only operate during daylight hours.

In the report 'Tracking Clean Energy Progress (2012), International Energy Agency stated that over the period 2000-2011, solar PV was the fastest-growing renewable power technology worldwide. Cumulative installed capacity of solar PV reached roughly 65 GW at the end of 2011, up from only 1.5 GW in 2000.

In 2011, Germany and Italy accounted for over half the global cumulative capacity, followed by Japan, Spain, the United States, and China. According to IEA analysis, under extreme assumptions solar energy could provide up to one-third of the world's final energy demand on 2060 (IEA, n.d.).

e. Wind Power

In recent years, wind has become an increasingly attractive source of renewable energy. It is now the world's fastest-growing energy technology (IEA, n.d.). as it is displayed in Figure 5, wind turbines usually have two or three blades and, because winds above the ground tend to be faster and less turbulent than those near the surface, turbines are mounted on tall towers to capture the most energy. As the blades turn, the central shaft spins a generator to make electricity. Wind turbines a placed at sites with strong and steady winds (about 20 km/hour) can economically generate electricity without producing pollutants. Wind turbines have a maximum possible efficiency of 59.3%, with a more common efficiency of around 40%. Wind turbines can be connected to a utility power grid or even combined with a photovoltaic (solar cell) system. For utility-scale sources of wind energy, a large number of wind turbines are usually built close together to make a "wind farm" and to produce more electricity. Wind power helps the environment by producing electricity without producing pollution.

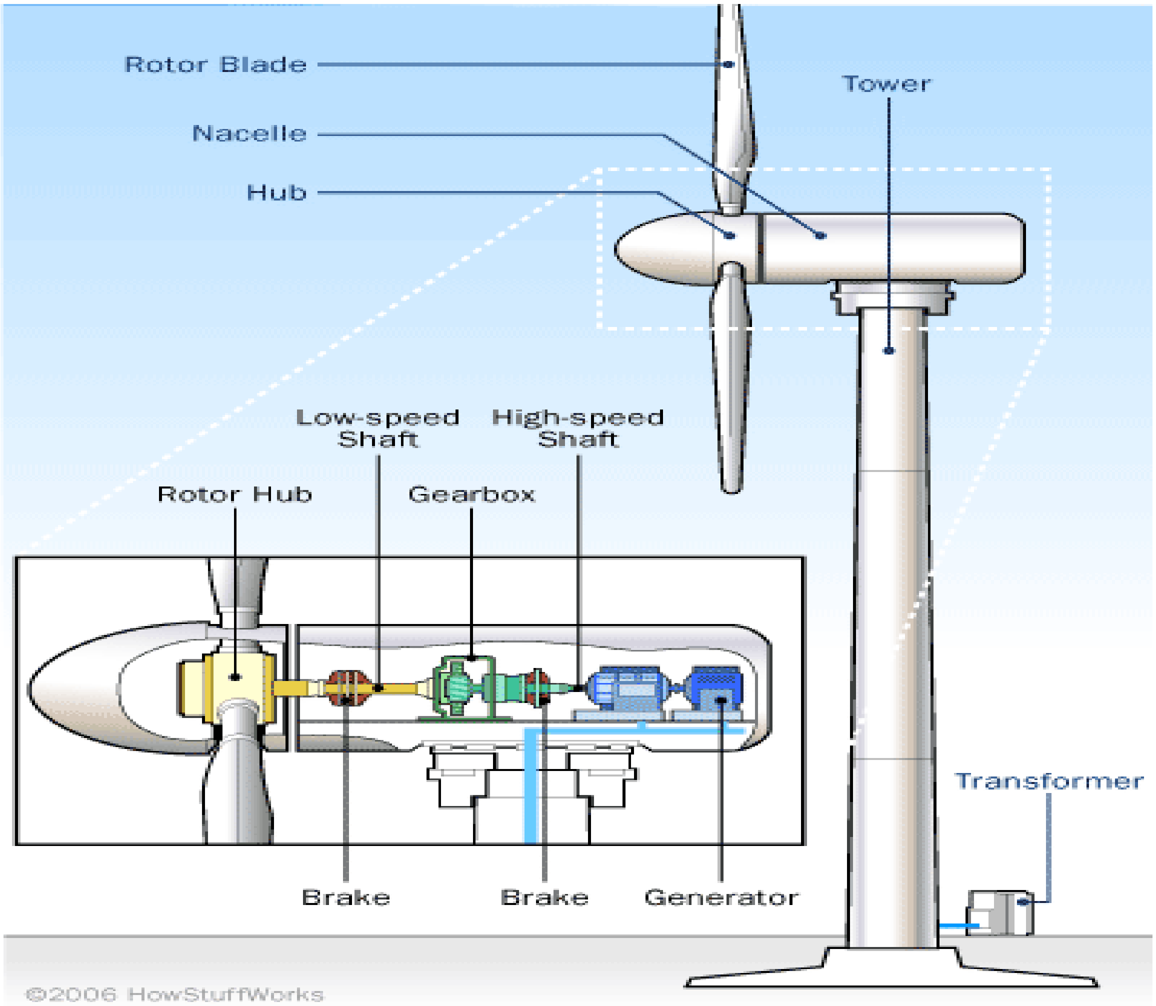

Figure 5. Wind Tribune (From Goffman, 2008)

According to International Energy Agency's data, installed capacity of wind power has increased from 18 GW in 2000 to 238 GW in 2011. Around 41 GW was added in 2011 alone (International Energy Agency, 2011). In 2010, China became the global leader in terms of total installed capacity. A number of recent important developments have emerged in support of expanded wind markets. Many of the new policy developments concern offshore winds. Ten European countries have agreed to develop an offshore electricity grid in the North Sea to enable offshore wind developments (IEA, n.d.).

f. Ocean Power

Oceans cover more than 70% of Earth's surface. This makes them the world's largest solar collectors. The ocean can produce two types of energy: *thermal energy* from the sun's heat and *mechanical energy* from the tides and waves.

There are five different technologies that aim to extract energy from the oceans under development (IEA, n.d.):

- Tidal power: the potential energy associated with tides can be harnessed by building a barrage or other forms of construction across an estuary.
- Tidal (marine) currents: the kinetic energy associated with tidal (marine) currents can be harnessed using modular systems.
- Wave power: a range of technologies under development will be able to harness the kinetic and potential energy associated with ocean waves. For wave energy conversion, there are three basic systems: *channel systems* that funnel the waves into reservoirs; *float systems* that drive hydraulic pumps; and *oscillating water column systems* that use the waves to compress air within a container.
- Temperature gradients: the temperature gradient between the sea surface and deep water can be harnessed using different ocean thermal energy conversion (OTEC) processes. OTEC is used for many applications, including electricity generation. There are three types of electricity conversion systems: *closed-cycle, open-cycle,* and *hybrid.* Closed-cycle systems use the ocean's warm surface water to vaporize a *working fluid*, which has a low-boiling point, such as ammonia. The vapor expands and turns a turbine. The turbine then activates a generator to produce electricity. Open-cycle systems actually boil the seawater by operating at low pressures. This produces steam that passes through a turbine/generator. Hybrid systems combine both closed-cycle and open-cycle systems.

- Salinity gradients: at the mouth of rivers, where freshwater mixes with saltwater, energy associated with the salinity gradient can be harnessed using the pressure-retarded reverse osmosis process and associated conversion technologies.

Currently, these technologies are not widely used, but in the future they may play a significant role in electricity generation.

g. Geothermal Thermal

The source of the geothermal energy is the heat from the Earth. As a clean and sustainable type of energy, sources of geothermal energy range from shallow ground to hot water and hot rock found a few miles beneath the Earth's surface. Although geothermal power is cost effective, reliable, sustainable, and environmentally friendly, it has been limited to areas near tectonic plate boundaries. Geothermal energy is an important resource in volcanically active places, such as Iceland and New Zealand (Glassley, 2010).

According to IEA, there is potential to achieve at least a twenty-fold increase in the global production of heat and electricity from geothermal energy between now and 2050. Through developing new technologies to harness geothermal resources, geothermal energy could account for around 3.5% of annual global electricity production and 3.9% of energy for heat (excluding ground source heat pumps) by 2050 (IEA, n.d.).

h. Biomass Power

Biomass power is obtained from the energy in plants and plant-derived materials, such as food crops, grassy and woody plants, residues from agriculture or forestry, and the organic component of municipal and industrial wastes. As the largest biomass energy resource today, wood has been used for energy longer than any other biomass source. Waste energy is the second-largest source of biomass energy. The main contributors of waste energy are municipal solid waste, manufacturing waste, and landfill gas (National Renwable Energy Labrotuary, n.d.).

Biomass can be used for fuels (such as ethanol and biodiesel), generating electricity and products (such as burning wood in a fireplace or wood stove). Electricity generated from biomass is called bio power.

Biomass-based energy accounted for roughly 10% of the world's total primary energy supply in 2009. A total of 280 TWh of bioenergy electricity, about 1.5% of world electricity generation, was generated globally in 2010; 8 EJ of bioenergy for heat was used in the industry sector (IEA, 2011).

2. Global Energy Consumption

As populations grow and society's needs change, global energy consumption is likely to rise. According to International Energy Agency's world energy statistics (2011), total primary energy consumption of the world increased 78.71% from 1972 to 2009. As illustrated in Figure 6, world total primary energy consumption is 8353 Mtoe (million tons of oil equivalent). Of this, oil constitutes 41.3%; electricity 17.3%; natural gas 15.2%; biofuels and waste 12.9%; coal 10%; and geothermal, solar, heat, etc. 3.3%. From 1990 to 2011, the average use of energy per person (per IEA data) increased 10 %, but the world population increased 27 % (IEA, 2011).

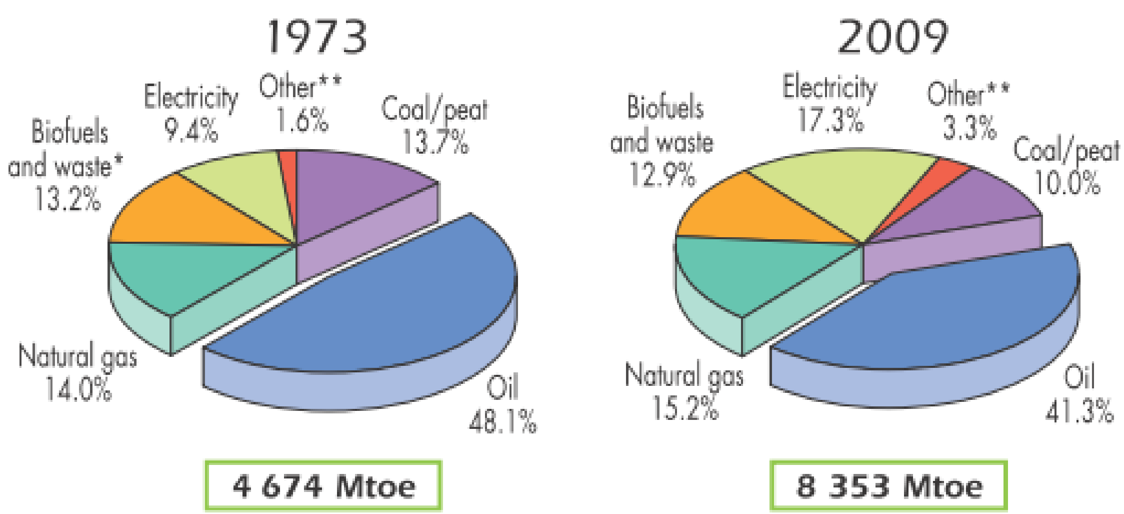

Figure 6. 1973 and 2009 Fuel Shares of Total Final Consumption (From IEA, 2011).

As demonstrated in Figure 7, while OECD countries constituted 60.3% of the world total final consumption in 1972, in 2009 their portion in total consumption decreased to 42.8%. On the other hand, the portion of China, Asia, and especially the Middle East in total energy consumption has grown substantially over the years (IEA, 2011).

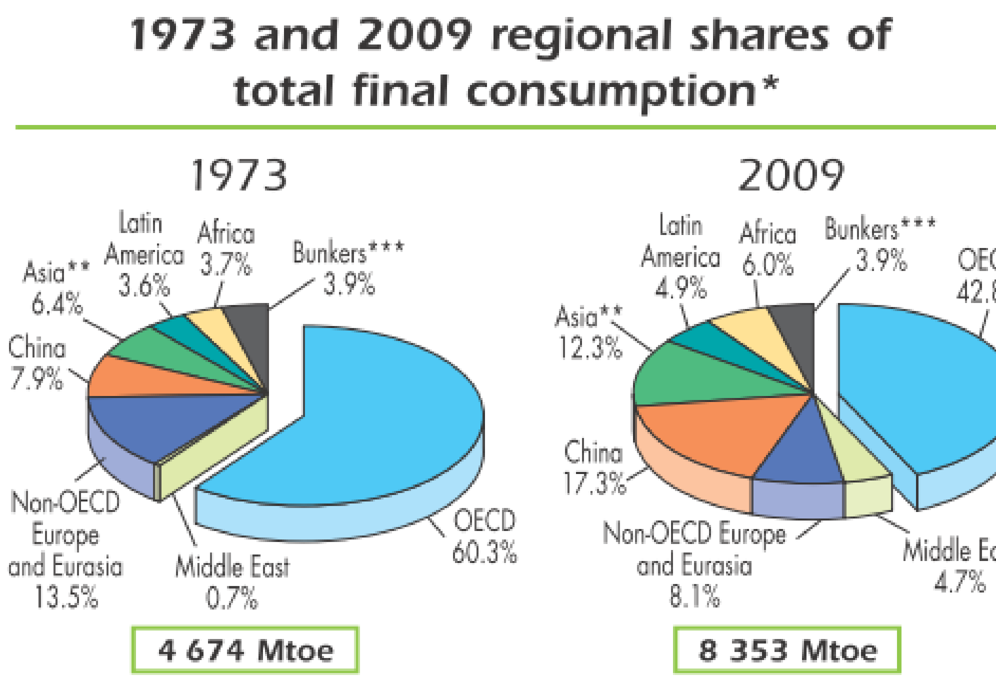

Figure 7. 1973 and 2009 Regional Shares of Total Final Consumption (From IEA, 2011).

Comparing with the previous year, in 2011, total world primary energy consumption grew by 2.5%, reaching 12274.6 Mtoe. In 2011, after the strong growth noticed in 2010, primary energy consumption increased at a much slower pace. While consumption in OECD countries fell by 0.8%, Non-OECD consumption grew by 5.3%. Accounting for 33.1% of global energy consumption, oil remained the world's leading fuel, but it continued to lose market share for the twelfth consecutive year. The installed renewable energy capacity is: solar capacity 69371 MW; wind capacity 239485MW; and geothermal capacity 11014MW (British Petroleum, 2012).

Figure 8 illustrates the increase in global energy consumption. From 2004 to 2009, the total energy consumption grew by 784 million tons oil. Equivalent coal consumption grew by 1025 million metric tons. Natural gas consumption grew by 38 billion cubic meters and petroleum consumption stayed almost at the same level.

Years	2004	2005	2006	2007	2008	2009
Total Energy Consumption (million tons oil equivalent)	9530	9802	9989	10310	10464	10314
% change	4.60%	2.90%	1.90%	3.20%	1.50%	-1.40%
Electricity Consumption (kWh per head)	2933	3023	3110	3225	3252	3215
Total Electricity Consumption (trillion kWh)	14	15	16	16	17	17
% change	4.50%	4.20%	4%	4.50%	1.90%	0.00%
Coal Consumption (million metric tonnes)	5343	5554	5832	6149	6404	6368
% change	6.40%	3.90%	5.00%	5.40%	4.20%	0.60%
Natural Gas Consumption (billion cubic meters)	2418	2429	2462	2518	2527	2456
% change	3.90%	0.50%	0.013	2.30%	0.40%	2.80%
Petroleum Consumption (million b/d)	73	74	75	76	76	73
% change	3.60%	1.60%	0.008	1.90%	0.50%	3.70%

Figure 8. Global Energy Consumption from 2004 to 2009 (From EIA, 2010).

According to Energy Information Administration (EIA) data (2010), petroleum usage in energy consumption slightly decreased between 2000 and 2009. On the other hand, coal consumption is gradually increasing. Currently, there is no big change in the consumption of other energy types.

4. Future Energy Demand

The global market for energy consumption is forecasted to grow almost 55% by 2035 (according to the U.S. Energy Information Administration's International Energy Outlook 2011). As displayed in Figure 9, the fastest rate of growth in energy consumption is represented by nations outside of the Organization for Economic Cooperation and Development (OECD) that show signs of economic growth. Within the OECD, growth is expected to remain inferior at 20% and outside the OECD it is forecast to rise by 85% (EIA, 2011).

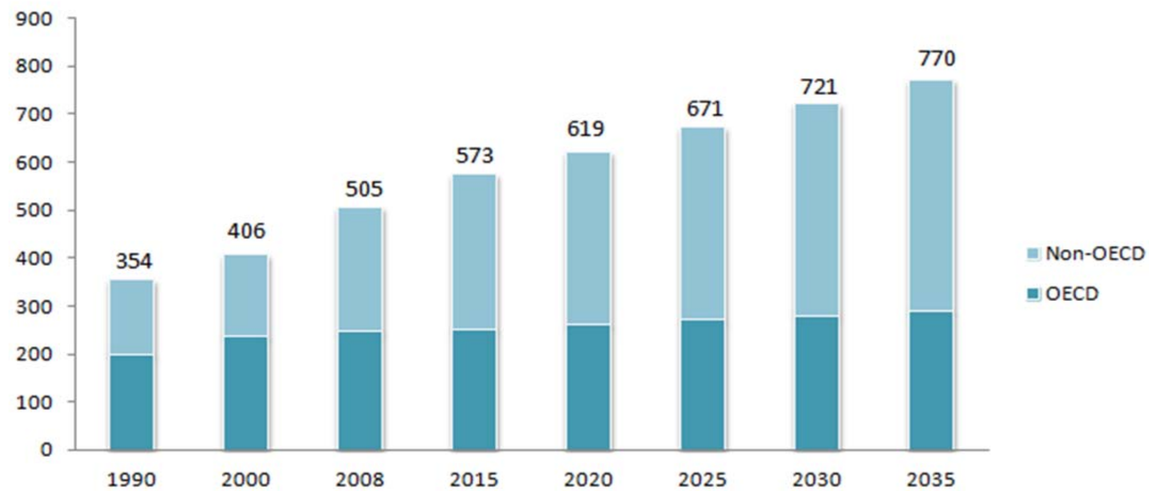

Figure 9. World Energy Consumption (Quadrillion Btu) 1990–2035 (From EIA, 2011).

According to EIA projections, as displayed in Figure 10, fossil fuels are expected to continue supplying much of the energy used worldwide. Although liquid fuels mostly petroleum based remain the largest source of energy, the liquid share of world-marketed energy consumption will fall from 34% in 2008 to 29% in 2035. As projected, high world oil prices cause many energy users to switch away from liquid fuels when feasible. Coal production is expected to increase from 139 quadrillion Btu in 2008 to 209 quadrillion Btu in 2035, at an average annual rate of 1.5%t with most of the growth expected in China and India. Natural gas, which is projected to increase 57%, continues to be the fuel of choice for many regions of the world for electric power and industrial sectors. This is because of relatively low greenhouse gas emissions. Renewable energy is the world's fastest growing form of energy. The renewable share of total energy use will increase from 10% in 2008 to 14% in 2035 (EIA, 2011).

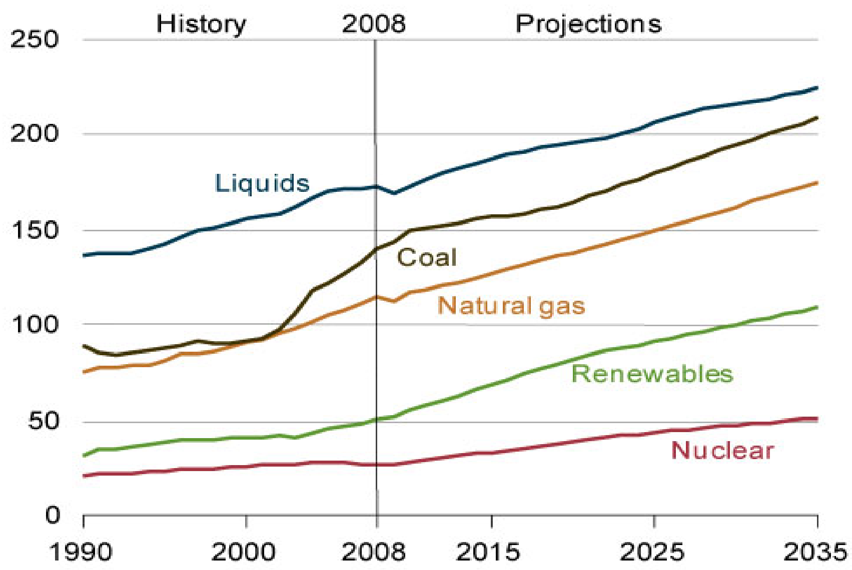

Figure 10. World Energy Consumption by Fuel 1990–2035 (Quadrillion Btu) (From EIA, 2011).

According to Exxon Mobil “2012 The Outlook for Energy: A View to 2040,” projections about global future energy demand will be about 30% higher in 2040 compared to 2010. This is because of the population (estimated to be nearly 9 billion people) and economic output growth. In OECD countries, energy consumption will remain stable. This is even as these countries achieve economic growth and even higher living standards. In contrast, Non OECD energy demand will grow by close to 60%. China’s surge in energy demand will last over the next two decades and then gradually flatten as its economy and population matures. Electricity generation, which is the biggest driver of demand, will account for more than 40% of global energy consumption in 2040. Because of new policies that will seek to reduce emissions by imposing a cost on higher carbon fuels, consumption for coal will peak. Then it will begin to decline. On the other hand, consumption of renewable energies and nuclear power will grow significantly.

Oil, gas, and coal continue to be the most widely used fuels. They will account for approximately 80% of total energy consumption in 2040 (Exxon Mobile, 2012).

Demand for natural gas will rise by more than 60% through 2040. It will be the second most widely used fuel after oil. For both oil and natural gas, an increasing share of global supply will come from unconventional sources such as those produced from shale formations (Exxon Mobile, 2012).

In the future, since increasing fossil fuel usage will lead to an energy crisis, mankind will be forced to research and develop alternative energy sources. Countries will need to find ways to extract energy from renewable sources.

C. ELECTRICITY GENERATION

Today it would be difficult to imagine a world without electricity. Electricity generation has become increasingly important in all areas of our society. Countries have become increasingly dependent on reliable and secure sources of electricity. Electricity generation is the amount of electricity generated by a power plant including own-use electricity, as well as transmission and distribution losses. Electricity is produced by converting energy from another form of energy. There are two types of conversion processes: direct and indirect process. In the direct process, energy is converted directly to electricity. An example of this is solar photovoltaic cells: these convert the energy found in solar radiation directly to electricity. An indirect conversion process consists of converting energy from one form, to an intermediate form, and then to electricity. As an example of indirect process, coal-fired generating plants use coal to produce heat that is used to produce steam to rotate the turbine. Then the rotating kinetic energy is converted to electricity. The majority of the electricity today is produced through an indirect energy conversion process. When producing the ever-increasing amounts of electricity needed in everyday life, several factors should be taken into account, such as industrial need, population growth, climate change, and dwindling fossil fuel reserves (Klimstra & Hotakainen, 2011).

It is important to recognize that since electricity is not easily stored in quantity, it must be generated at the time of demand. Electricity is a form of energy, but not an energy source. Different generating plants harness from different energy sources to make electric power. With regards to their electricity generating methods, the power plants can be classified as “Thermal Plants” and “Kinetic Plants.”

1. Types of Power Plants

a. Thermal Power Plants

Thermal power plants convert heat energy into electrical energy. Water is heated in a boiler until it becomes high-temperature steam. This steam is channeled through a turbine which has many fan-blades attached to a shaft. When the steam moves over the blades, it causes the shaft to spin. This spinning shaft is connected to the rotor of a generator and the generator produces electricity. The steam is then condensed and fed to the boiler again.

Pulverized coal plants constitute most of the existing coal-fired generating capacity. In this system, coal is ground to fine power and injected with air into a boiler where it ignites. Water-carrying tubes embedded in the boiler walls and downstream of the boiler absorb combustion heat. The heat turns the water to steam. This is used to rotate a turbine and produce electricity. New pulverized coal plants have a special design that gains efficiency by operating at very high steam temperature and pressure (Kaplan, 2008).

In Integrated Gasification Combined Cycle (IGCC), coal or other fossil fuel is converted to a “synthesis gas” (syngas) before combustion. Then some pollutants, such as sulfur, are removed from syngas. So, low amounts of sulfur dioxide are emitted. After combustion, excess heat from and syngas-fired generation is then passed to a steam cycle, similar to a combined cycle gas turbine. This process results in an increase in efficiency. Figure 11 illustrates the process. IGCC plants are more expensive to build than pulverized coal generation, but they cause lower emissions of air pollutants and greater efficiency.

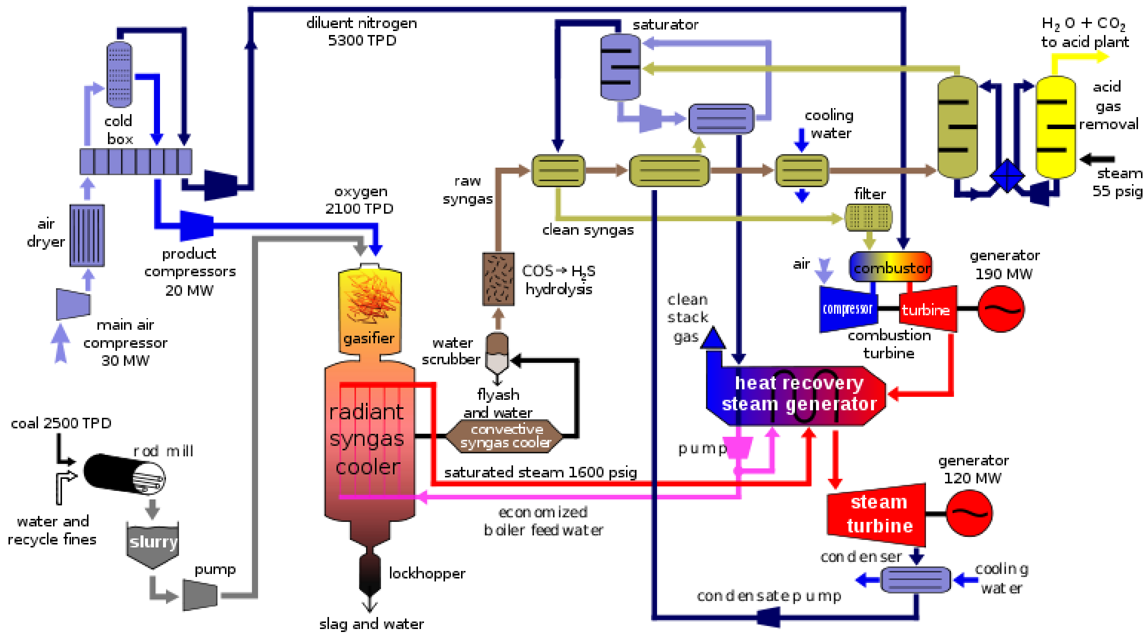

Figure 11. Diagram of IGCC Power Plant (From www.wikipedia.com)

NGCC power plants have both a gas turbine and a steam unit—all in one. The gas turbine use the hot gases released from burning natural gas to turn a turbine and generate electricity.

The difference of combined-cycle plants from other plants is that the waste heat from the gas-turbine process is directed toward generating steam. Then, much like a steam unit, it is used to generate electricity. This process is essentially similar to the technology used in jet engines. The hot exhaust gases from the combustion turbine are captured and used to produce steam. This drives another generator to produce more electricity. Combined-cycle plants are much more efficient than steam units or gas turbines alone. In fact, combined-cycle plants can achieve thermal efficiencies of up to 50 to 60%. This high efficiency compensates for the high cost of natural gas (Kaplan, 2008).

In nuclear plants, the process of generating electricity is very similar to the fossil fuel plant system. The only difference is that nuclear plants use atomic fission to produce heat for creating steam rather than by burning coal, oil, or gas. Nuclear plants are characterized by high investment costs, but low variable operating costs, including low fuel expense.

Nuclear power plants produce low amounts of greenhouse gas and air-borne particulates during normal operation. This makes them attractive to many who are concerned about air-quality. Nuclear power plants, like the other thermal power plants, use significant amounts of water for cooling the system. After other processes, wastewater is released into nature. This wastewater is hotter than that from a fossil plant. So, the nuclear power plants needs large cooling towers or other cooling techniques to address this problem. So far, disposing of spent fuel cores and contaminated parts used in the plants has not been solved. Since this radioactive material may remain dangerous for thousands of years, this source of energy is very controversial in many countries.

There are two types of nuclear reactors: one is a pressurized water reactor (PWR) and the other is boiling water reactor (BWR). Pressurized water reactor (PWR) is a type of a nuclear power reactor that uses enriched uranium as a fuel that heats the water used to produce steam. The main feature that differentiates it from a BWR nuclear reactor is that a PWR has a separate arrangement to make steam in the form of a heat exchanger (IEA, n.d.). Boiling Water Reactors (BWR) work similar to a pressure cooker where steam is generated from heat within the reactor core. This in turn is used to drive the turbine blades that turn the generator (IEA, n.d.).

As of July 2012, there were 435 nuclear power plant units with an installed electric net capacity of about 370 GW in operation worldwide (European Nuclear Society, n.d.).

Combined-cycle gas turbine power plants consist of one or more gas turbine generators equipped with heat recovery steam generators to capture heat from the gas turbine exhaust. Steam produced in the heat recovery steam generators powers a steam turbine generator to produce additional electric power. The system needs a fuel source (fossil, nuclear, biomass, geothermal, or sun) to heat the water. If natural gas is the fuel, it is called a natural gas combined cycle (NGCC). If coal gasification is used to produce synthetic gas, it is called an integrated gasification combined cycle (IGCC) (Northwest Power Planning Council, 2002).

Biomass power plants use many different technologies. The most common is burning wood or other feedstock (renewable plant material) to produce steam. This is then used to drive turbines and produce electricity. Some biomass power plants use the mixture of fossil fuels and biomass to produce heat as well.

b. Kinetic Generating Plants

In these types of plants, kinetic energy or the energy of motion is used instead of heat energy. Moving wind or water spins a turbine which in turn spins the rotor of a generator. Since no fuel is burned, no air pollution is produced.

Hydroelectric plants use the kinetic energy of falling or flowing water to rotate the turbine blades, hence, converting kinetic energy into electrical energy ("Hydroelectric Power: How it Works," n.d., para 3). Hydroelectric plants are the most widely used form of renewable energy. The power that is generated by these plants depends on the volume and difference in height between the source and the water's outflow ("Water Electricity," n.d., para 2). So, deciding their location depends on a number of factors that are beyond the control of human beings, such as the hydrological cycle of the region. If there is a shortage of water, it could shut down these plants. There are several advantages in hydropower. One advantage is that the cost is relatively low and, since plants can be ramped up and down very quickly to adapt to changing energy demands, it is a flexible source of electricity.

Hydroelectricity accounts for 16% of global electricity consumption and, in 2010, accounts for 3,427 terawatt-hours of electricity production. According to World Watch Institute report (2012), China, Brazil, the United States, Canada, and Russia accounted for approximately 52% of the world's installed hydropower capacity in 2010 (World Watch Institute, 2012).

Wind power plants use wind-driven turbines to generate electricity. Wind farms consist of several hundred wind tribunes that are connected to the electric power transmission network. An individual turbine typically has a capacity in the range of 1.5 to 2.5 MW. A wind plant includes dozens or hundreds of these turbines (Kaplan, 2008). Wind is a variable renewable resource because its availability depends on weather conditions. Since it does not create air pollution and doesn't require reservoirs, wind power is an attractive solution for future electricity demand. As of 2011, 83 countries around the world were using wind power on a commercial basis (REN21 Commitee, 2011). Construction costs of wind farms are high. The main reason is the steel that is used in wind towers. In order to reduce this cost, some companies in Germany and Canada have developed timber towers. Timber Tower Company is currently building a 100 meter tall mast that will eventually be topped with a 1.5 MW wind turbine. They also have plans to build a 140 meter tall tower (Markham, 2012).

There are few suitable locations where the wind blows predictably in the world. Even in such sites, turbines often have to be designed with special gearing so that the rotor will turn at a constant speed in spite of variable wind speeds.

c. Alternative Electricity Generation

Geothermal Electricity use geothermal energy when generating electricity. Technologies in use include dry steam power plants, flash steam power plants, and binary cycle power plants. Dry steam power plants draw from underground resources of steam. Then, steam is piped directly from underground wells to the power plant where it is directed into a turbine/generator unit. Binary cycle power plants operate on water at lower temperatures of about 225°F-360°F (107°C-182°C) (IEA, n.d.). In a typical binary cycle geothermal facility, wells draw hot water and steam from underground into a heat exchanger. This is where a working fluid is vaporized and used to drive a turbine generator (Kaplan, 2008). Flash steam plants are the most common types of geothermal power plants in operation today. They use extremely hot water (above 300°F (149°C) which is pumped under high pressure to the generation equipment at the surface. The hot water is vaporized and the vapor in turn drives turbines to generate electricity ("Geothermal Electricity Production," n.d., Flash Steam section, para.1).

The thermal efficiency of geothermal electric plants is low—around 10–23%. This is because geothermal fluids are at a low temperature compared with steam from boilers. According to International Geothermal Association data (2010), the world's total geothermal electricity installed capacity has increased from 5,831 MWh in 1990 to 10,716.7 MWh in 2010.

There are two types of solar power: solar thermal power and PV power. These are alternative means of harnessing sunlight to produce electricity. Solar thermal plants, also known as concentrated solar power (CSP), concentrate sunlight to heat a working liquid to produce steam that drives a power-generating turbine. Two major types of solar thermal systems are parabolic trough and power tower technologies. Parabolic trough plants use an array of mirrors to focus sunlight on liquid-carrying tubes integrated with mirrors. The power tower technology uses a mirror field to focus sunlight onto a central tower where the heat is used to produce steam for power generation. A potential advantage of solar thermal systems is the ability to produce electricity when sunlight is weak or unavailable by storing solar heat in the form of molten salt (Kaplan, 2008).

Solar or photovoltaic (PV) cells function as generators. A photovoltaic system is composed of cells made of silicon. These cells take advantage of the ability of light to create an electric current in some substances. When sunlight strikes the semiconductor material, it generates electricity. They produce no pollution when operating and most scientists predict that the fuel supply will last at least 4 billion years. Two disadvantages of the solar panels are that they are expensive to make and they don't work without sunlight. (Global Climate & Energy Project, 2006).

D. WATER AND ENERGY NEXUS

Energy and freshwater resources are intricately connected: we use energy to help us clean and transport the fresh water we need and we use water to help us produce the energy we need. As we approach a new century, physical and environmental constraints in our use of both resources are beginning to manifest themselves. Figure 12 shows the water and energy relationship (Gleick, 1994).

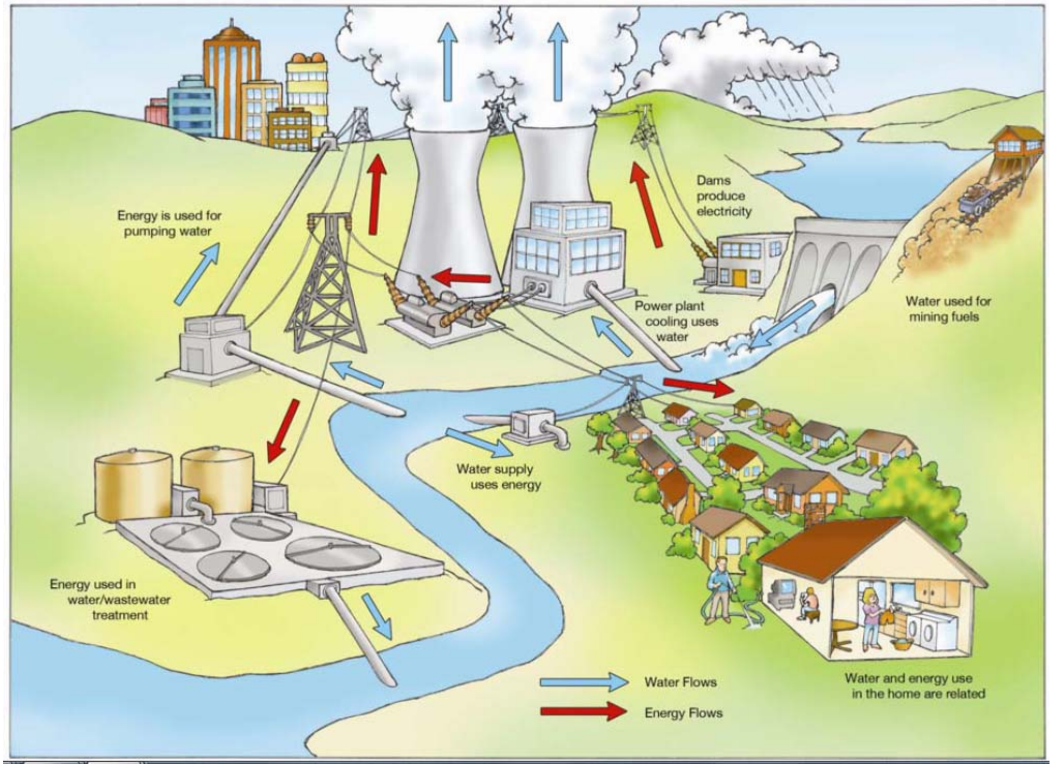

Figure 12. Water and Energy Nexus (From U.S. Department of Energy [DOE], 2006).

Water is usually perceived as an inexhaustible resource. But this resource is gradually getting limited. Because energy consumption is rapidly going up, water requirements for electricity production are increasing. The demand for freshwater in energy production is competing with other water requirements, such as sanitation and agriculture. For example, a drought in the southeastern U.S. in 2007 underscored this issue with, because of the drop in river water levels, most of the nuclear power plants had to decrease their output to 50% (Reppert, 2009).

In this decade, the arguments are made about energy in terms of efficiency over freshwater resources (Gleick, 1994). Operations in purification facilities and modern water supply require energy. Specifically, brackish water or seawater desalination and massive pumping from groundwater aquifers processes all need energy. Also, energy is needed to transfer water from water-rich to water-poor regions. All would be impossible without energy. On the other hand, water is usually required in the production and usage of energy. To mine an energy resource, to construct, operate and maintain the energy generation facilities, require water. Also water is used in power plants for cooling and to dispose of waste products (Gleick, 1994).

The energy sector can impact water quality. Processes, such as mining operations runoff, stream of waste, and emission of air and used water from oil and gas extraction, may have an effect on watersheds. Interaction examples are shown in Tables 1 and 2 (DoE, 2006).

Energy Element	**Connection to Water Quantity**	**Connection to Water Quality**
Energy Extraction and Production		
Oil and Gas Exploration	Water for drilling, completion, and fracturing	Impact on shallow groundwater quality
Oil and Gas Production	Large volume of produced, impaired water*	Produced water can impact surface and groundwater
Coal and Uranium Mining	Mining operations can generate large quantities of water	Tailings and drainage can impact surface water and ground-water
Electric Power Generation		
Thermo-electric (fossil, biomass, nuclear)	Surface water and groundwater for cooling ** and scrubbing	Thermal and air emissions impact surface waters and ecology
Hydro-electric	Reservoirs lose large quantities to evaporation	Can impact water temperatures, quality, ecology
Solar PV and Wind	None during operation: minimal water use for panel and blade washing	

*impaired water may be saline or contain contaminants

**Includes solar and geothermal steam-electric plants

Table 1. Interaction between Energy and Water Quality and Quantity (After DOE, 2006).

Energy Element	Connection to Water Quantity	Connection to Water Quality
Refining and Processing		
Traditional Oil and Gas Refining	Water needed to refine oil and gas	End use can impact water quality
Biofuels and Ethanols	Water for growing and refining	Refinery waste-water treatment
Synfuels and Hydrogen	Water for synthesis or steam reforming	Wastewater treatment
Energy Transportation and Storage		
Energy pipelines	Water for hydrostatic testing	Wastewater requires treatment
Coal Slurry Pipelines	Water for slurry transport; water not returned	Final water is poor quality: requires treatment
Barge Transport of Energy	River flows and stages impact fuel delivery	Spills or accidents can impact water quality
Oil and Gas Storage Caverns	Slurry mining of caverns requires large quantities of water	Slurry disposal impacts water quality and ecology

Table 2. Interaction between Energy and Water Quality and Quantity (After DOE, 2006).

In some situations, water withdrawn from a source is returned to the water supply. In some situations, it is consumed during operation or contaminated until its further usage. Even a hydroelectric facility is accountable for water loss. This stems from evaporation that occurs on reservoir surfaces. This situation leads to loss of consumptive water. Water usage related to energy sector may cause some significant changes in terms of natural hydrological and ecological systems. Pressure is increasing on interbasin transfers of water-to-water poor regions. In the next decades, site choices will be constrained due to limitations on water availability (Gleick, 1994).

In the next 30 years, there will be new demands from other areas, such as competing society sectors and growing populations. This will add new pressures on the amount of water that is used in energy production. In some parts of the world, type and extent of energy development may be restricted because of the constraints on the availability of freshwater. At the same time, we may not be capable of providing sufficient clean water and sanitation services to many people who are devoid of those basic services. This is due to high-energy costs or constrained energy availability (Gleick, 1994).

Water availability can be deeply affected from climate change. This situation may cause greater constraints in some regions of the world.

1. Water Usage in Electricity Generation

Power plants, mines, and refineries are very large energy facilities. They can have an important effect on local water resources (DOE, 2006). For instance in the U.S, freshwater withdrawals for thermoelectric energy production and freshwater withdrawals for irrigated agriculture show nearly the same percentage of the 349 billion gallons per day (GPD) of water withdrawn (displayed in Figure 13). Large amounts of water withdrawn for thermoelectric production is returned and can be re-used. But thermal or chemical pollution may lower water quality. Rivers and lakes provide 70% of the freshwater that is used for thermoelectric cooling. Rest of the water used in cooling is saline. Its surface water consists of 99% of this freshwater. Water used for irrigation consists of 40% of total withdrawals. It includes more than 80% of the 100 billion gallons of water consumed daily in the U.S. (displayed in Figure 14). Evapotranspiration causes these losses. Approximately 40% of the water withdrawn that is used for irrigation is returned for re-use (Faeth, 2012).

International Energy Agency (IEA) made projections of stationary power supply for the world. It is projected that there will be a 40% increment in electricity generation between 2009 and 2030. This augmentation in electricity generation will create large increases in water withdrawals for thermoelectric cooling. This is of the biggest part of water withdrawals.

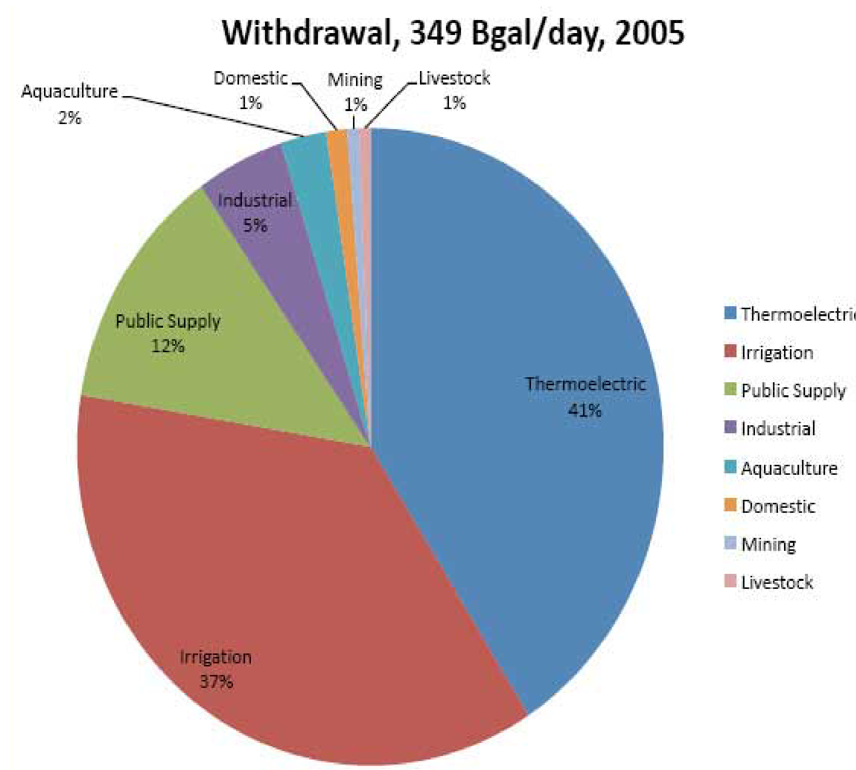

Figure 13. Freshwater Withdrawal in U.S. (From Faeth, 2012).

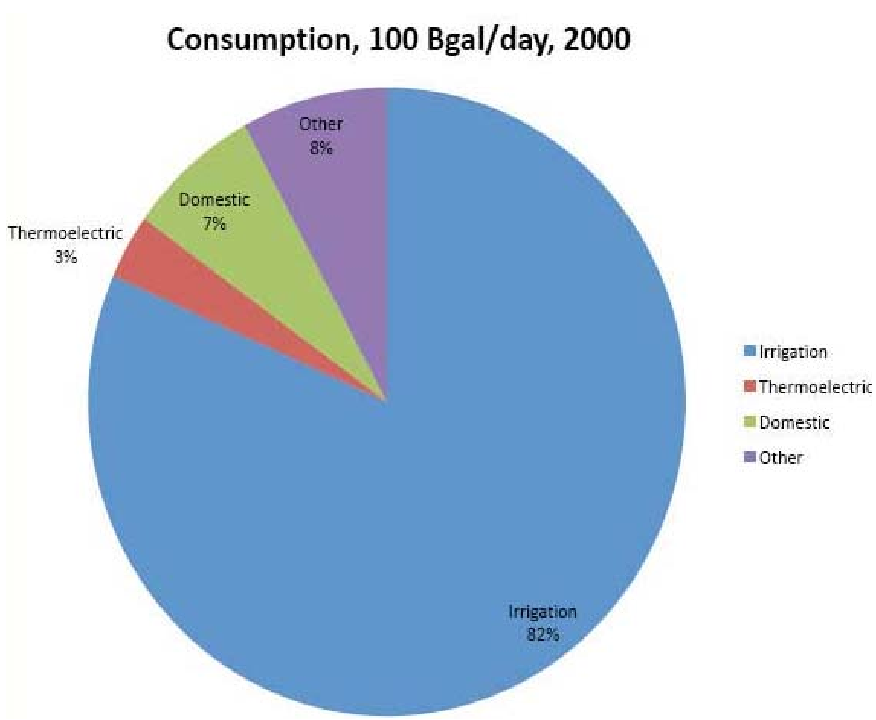

Figure 14. Freshwater Consumption in U.S. (From Faeth, 2012.)

Particularly in dry areas, because there should be sufficient water for cooling and chemical processes, the decision about the location of power plants depends on the proximity to water resources. Hence, power plants should be located near a reliable source of water. Another solution might be selecting an energy source that needs less water. The weight of the coal burned in coal-fired plants is much smaller in comparison to the weight of the water used for cooling. Therefore, moving the coal to a water source provides distinct economic advantages. 1012 J(th) (joules thermal) can be generated by 40 tons of coal. Approximately 500 tons of water is needed in a coal-fired power plant using once-through cooling for every 1012 J(th). Also, water will be used for all other processes of the coal fuel cycle. That means more water than this will need to be withdrawn for use. Thus, the weight of coal required is 10 times less than the weight of water used by a power plant (Gleick,1994).

The type of facility and the characteristics of the fuel cycle change the amount of water required for production of energy. A huge amount of water is required in energy facilities using fossil fuel, nuclear, and geothermal power. Evaporation or contamination may cause the loss of some of this water. Large amounts of this water are usually returned to a watershed for re-use by other sectors of society. Wind turbines, solar photovoltaic power systems, and other renewable energy sources require very small amounts of water. Some unconventional energy technologies might require large amounts of water, such as geothermal plants or hydroelectric plants (Gleick, 1994).

During extreme shortage periods, production of energy has decreased due to water-supply problems. Between 1987 and 1991, California was under a severe drought. During this period, hydroelectricity production considerably decreased. Electric utilities in the area were forced to buy more fossil fuels than usual. As a result, consumers had to pay an additional 3 billion dollars. Because of the long drought in Egypt in the 1980s, there was decreased electricity generation from Aswan Dam which provides approximately half of their electricity. These examples emphasize the problems related with water availability (Gleick, 1994).

Northern and northeastern Africa regions are short reliable water supplies. Because of that reason large, conventional fossil-fuel types of power plants cannot be sited in these areas. In western North America, there are constraints on synthetic fuel developments from oil shale and tar sands because the area provides limited available water resources (Gleick, 1994).

2. Electricity Generation's Effect an Water Quality

Water quality is affected by energy usage. Because of the water output of power plant cooling systems, the temperature of rivers and lakes increases. This augmentation impacts aquatic ecosystems. Heavy metals, acids, organic materials, and suspended solids can contaminate wastewaters from boilers, mining operations, and cooling systems. Groundwater and surface water resources are radioactively contaminated by nuclear power plants, nuclear fuel production plants, and uranium mill tailings ponds (Cooley & Fulton, 2011).

3. Water Consumption in Thermoelectric Power Plants

In thermoelectric power plants, electrical energy is the conversion of thermal energy. In thermoelectric generating power plants, steam is utilized to drive a turbine generator (Department of Energy, 2008). Cooling is required to condense the steam at the turbine exhaust. A variety of sources, such as coal, nuclear, natural gas, oil, biomass, concentrated solar energy, and geothermal energy, provide heat in these power plants. The required freshwater amount is important. Seawater consumption is 59 billion gallons and the freshwater amount is 136 billion gallons per day in the U.S. (Hutson et al., 2004).

In a typical thermoelectric power plant, heat is removed from the cycle with a condenser and, from there, cooling water is used to remove the heat. The cooling water output flows into a river, a reservoir, or the ocean. A portion of cooling tower water is evaporated. This evaporation is used for transferring heat into the air. To keep the environmental effects at a minimum, cooling towers are being pursued more.

Water that is consumed in thermoelectric power plants is calculated by the USGS (United States Geological Survey). According their calculations, the total amount of freshwater that was used at U.S. thermoelectric power plants in 1995 was 132,000 MGD (Million Gallons per Day). Of this amount, 2.5% is evaporation, 3,310 MGD (12.5 x 109 L/d). Related calculations are shown in Table 3 (Solley et al., 1998).

		Water Intensity (gal/MW)			
Plant Type	Cooling Process	Steam Condensing		Other Use	
		Withdrawal	Consumption	Withdrawal	Consumption
Fossil/ biomass-steam turbine	Open-loop	20000–50000	300		
	Closed-loop	300–600	300–480		
	Dry	0	~ 0	~ 30	
Nuclear steam turbine	Open-loop	25000–60000	400		
	Closed-loop	500–1100	400–720		
	Dry	0	0	~30	
Natural Gas combined-cycle	Open-loop	7500–20000	100	7–10	
	Closed-loop	~ 230	~ 180		
	Dry	0	0		
Integrated Gasification combined-cycle	Closed-loop	200	170	150	
	Dry cooling	0	0	150	

Table 3. Water Withdrawal and Consumption Factor in Electricity Generation (From DoE, 2006).

In all thermoelectric power plants, such as nuclear, geothermal, or fossil fuels, water or other used fluids is converted into steam or vapor to drive electric-generating turbines. Cooling systems must condense this vapor to carry out the recycling process through the turbines. There are different types of cooling technologies used in thermoelectric power plants. Some of them are wet and dry cooling towers, once-through circulation, and cooling ponds (Gleick, 1994).

Once-through cooling has distinct economic advantages where sufficient fresh or salt water is available. In once-through cooling, large volumes of water are withdrawn from a river, lake, or aquifer (or the ocean), circulated a single time through the cooling system, and then discharged at a considerably higher temperature. Plants equipped with once-through cooling water systems have relatively high water withdrawal, but low water consumption. Where water is scarce or where the discharge of warm water is unacceptable, once-through cooling is often prohibited and closed-cycle systems are used.

Closed-cycle wet cooling systems rely primarily on evaporation to dissipate waste heat, either through cooling towers or ponds. There are three types of cooling towers in use: wet towers, dry towers, and hybrids. In each system, air is passed through the tower to remove heat from the water, either through direct contact in wet towers or through indirect methods that work in much the same way as an automobile radiator. Dry cooling towers are considerably more expensive than wet or hybrid systems and are built only in extremely water-scarce regions. The other closed-cycle system is the cooling pond which uses evaporation, conduction, and radiation to transfer heat to air from open ponds.

The choice of cooling system depends on a variety of factors, including withdrawal volumes required, consumptive losses, relative economic costs, and environmental and aesthetic factors. The consumptive use of water in wet cooling towers is roughly twice that of once-through systems though total water withdrawals are considerably less. Consumptive losses from cooling ponds are about 30% higher than from wet cooling towers, and closed-cycle systems can reduce total water withdrawals by nearly 95% compared to the water required for once-through cooling. As a result, in regions without sufficient water for once-through cooling, such as arid and semi-arid regions, closed-cycle systems may be required, with their higher rates of consumptive use, but lower overall withdrawals.

Closed-cycle cooling systems entail environmental costs of their own not associated with once-through systems. Facilities that use ocean water for cooling can spread salt-bearing steam across nearby land, damaging agricultural capacity. The cooling towers of such systems often can cause local fogs and road ice under certain climatic conditions. In addition, large cooling towers that are visible for miles are often considered aesthetic liabilities (Gleick, 1994).

Total cooling water withdrawals are substantial in developed countries. In 1995, water withdrawals used in thermoelectric power plants were about 182 km3 in the U.S. Of this amount, 4.5 km^3 was evaporation (NREL, 2003). This amount consists of nearly 40% of all freshwater withdrawals in U.S. (USGS, 2004). Of this water, 73% is used for cooling fossil fuel power plants, 27% for nuclear power plants, and 1% is used in geothermal plants. In some European countries, such as France, Germany, and Austria, total water withdrawals used in cooling have greater fractions than in the U.S. (Kohli & Frenken, 2011).

Water requirements in nuclear power plants are 25% higher than in coal and 250% more than in gas. Because of that reason, drought can deeply affect nuclear power plants. For instance, the U.S. extended drought in 2007 affected the operations of many nuclear power plants severely. Due to constraints on water availability, 24 of them (total number was 104) were confronted with the danger of shutdown. In thermoelectric power plants, efficiency in conversion processes can be increased with the augmentation of temperature and stream pressure (Faeth, 2012).

Nuclear power plants provide 12% of the total global electrical demand. This percentage is increasing in industrialized nations. The amount of electricity generated from nuclear power plants has significantly higher fraction in France, Belgium, and South Korea. In these countries, more than half of the total electricity demand is fulfilled with nuclear power plants. Power plant cooling requires the largest use of water in the nuclear fuel cycle. Water is also needed for the fuel cycle’s other processes (Faeth, 2012).

4. Water Consumption in Hydroelectric Power Production

Hydropower facilities can affect freshwater systems in many ways. Wildlife, water ecosystem, and environment may be affected by the creation of a reservoir. The biggest consumption of water resources stems from evaporation in hydroelectric power plants. Evaporation causes loss of water from the surface of reservoirs. This evaporation denotes the loss of a resource. Otherwise it might have been used for ecological and human uses. The evaporation amount changes according to surface area, temperature, wind conditions, and humidity of a region. The climate of the area can increase the water losses that stems from evaporation. For example, at the Aswan High Dam on the Nile, water losses from evaporation consist of 11% of reservoir capacity (Torcellini, Long, and Judkoff, 2003).

In addition to evaporation, seepage losses from porous ground cause consumptive use of water. According to the estimations, a water loss that stems from seepage is 5% of the annual volume of reservoirs. In some regions, big environmental problems have occurred because of the seepage losses. For instance, the Anchor Dam in Wyoming is so porous that the reservoir has never totally filled since its operation (Gleick, 1994).

There are many types of design and operation of hydroelectric plants. Some of them are large, multipurpose storage reservoirs and run-of-river projects (U.S. Department of Energy, 2006).

5. Water Consumption in Solar Power Production

Water or another working fluid can be heated and vaporized using the energy from the sun to produce electricity. Although there are various designs for such systems, all of them use solar power towers. These solar towers use mirrors in order to focus sunlight onto a boiler. Individual concentrating collectors with tubes of a working fluid are sited at the collector's focal point. The working fluid has to be condensed and then it must be re-used. Water consumption estimations include make-up cooling water and minor water usage, such as the water for washing the mirrors. The type of facility significantly impacts the range. Solar ponds will require huge amounts of water. This is because the most effective ponds will be located in areas that have high evaporative loss rates. One estimation of water consumed with cooling, evaporation, and evaporation of water in solar ponds is higher than 25 m^3 per 10000 kWh.

Finally, sunlight is used directly to produce electricity by photovoltaic cells. Thus, water requirement for photovoltaic electricity production can be neglected. Photovoltaic arrays only require small amounts of water for cleaning (Gleick, 1994).

6. Water Consumption in Wind Power Production

Wind energy facilities require no water for the production of electricity.

7. Water Consumption in Geothermal Power Production

Wells drilled into a steam field are used in vapor-dominated systems. Turbine generators need steam to produce electricity. In vapor-dominated systems, outside cooling needs are between 7 and 13 m^3 of water per 1000 kWh output. There are several types of liquid-dominated geothermal systems in use, such as flash-steam systems and binary systems. Geothermal fluid's temperature denotes the appropriate technology that will be used in producing electricity (Torcellini, Long, and Judkoff, 2003).

In recent years, the simplest and most cost effective of liquid-dominated systems is flash conversion. In this system, pressure brings high-temperature geothermal fluid to the surface. On the surface, this heated geothermal fluid "flashes" into steam to drive a turbine. Mexico, Italy, Iceland, New Zealand, the Philippines, and the U.S. use flash geothermal systems (Gleick, 1994).

Binary systems, in which a working fluid is vaporized by low-temperature (150°C) geothermal fluid, are closed and nonpolluting. An outside source of cooling water is required in these systems. For water-dominated systems, water requirements for cooling is approximately 15 m^3 per 1000 kWh output. In addition to cooling, water is also needed for facility maintenance, fire protection, and sanitation (Gleick, 1994).

Tables 4 and 5 show the water consumption factors. Table 4 shows renewable electricity generating technologies and Table 5 shows nonrenewable electricity generating technologies. Water consumption amounts change according to the technology used. Evaporative cooling towers consume the largest amount of water in their operations. PV, wind energy, and CSP Stirling solar technologies, and natural gas combined cycle plants that use dry cooling technologies consume the lowest amount of water. Nuclear technologies have the biggest water withdrawal values. On the other hand, non-thermal renewable technologies have the smallest withdrawal values (Macknick, Newmark, Heath, and Hallett, 2011).

Fuel Type	Cooling	Technology	Median	Min	Max
PV	N/A	Utility Scale PV	26	0	33
Wind	N/A	Wind Turbine	0	0	1
CSP	Tower	Trough	865	725	1,057
		Power Tower	786	740	860
		Fresnel	1,000	1,000	1,000
	Dry	Trough	78	43	79
		Power Tower	26	26	26
	Hybrid	Trough	338	105	345
		Power Tower	170	90	250
	N/A	Stirling	5	4	6
Biopower	Tower	Steam	553	480	965
		Biogas	235	235	235
	Once-through	Steam	300	300	300
	Pond	Steam	390	300	480
	Dry	Biogas	35	35	35
Geothermal[1]	Tower	Dry Steam	1,796	1,796	1,796
		Flash (freshwater)	10	5	19
		Flash (geothermal fluid)	2,583	2,067	3,100
		Binary	3,600	1,700	3,963
		EGS	4,784	2,885	5,147
	Dry	Flash	0	0	0
		Binary	135	0	270
		EGS	850	300	1,778
	Hybrid	Binary	221	74	368
		EGS	1,406	813	1,999
Hydropower	N/A	Aggregated in-stream and reservoir	4,491	1,425	18,000

Table 4. Water Consumption Factors for Renewable Technologies (gal/MW) (From Macknick, Newmark, Heath, and Hallett, 2011).

Fuel Type	Cooling	Technology	Median	Min	Max
Nuclear	Tower	Generic	672	581	845
	Once-through	Generic	269	100	400
	Pond	Generic	610	560	720
Natural Gas	Tower	Combined Cycle	198	130	300
		Steam	826	662	1,170
		Combined Cycle with CCS	378	378	378
	Once-through	Combined Cycle	100	20	100
		Steam	240	95	291
	Pond	Combined Cycle	240	240	240
	Dry	Combined Cycle	2	0	4
	Inlet	Steam	340	80	600
Coal	Tower	Generic	687	480	1,100
		Subcritical	471	394	664
		Supercritical	493	458	594
		IGCC	372	318	439
		Subcritical with CCS	942	942	942
		Supercritical with CCS	846	846	846
		IGCC with CCS	540	522	558
	Once-through	Generic	250	100	317
		Subcritical	113	71	138
		Supercritical	103	64	124
	Pond	Generic	545	300	700
		Subcritical	779	737	804
		Supercritical	42	4	64

Table 5. Water Consumption Factors for Nonrenewable Technologies (gal/MW) (From Macknick, Newmark, Heath, and Hallett, 2011).

Table 6 shows water withdrawal factors for electricity generating technologies. Natural gas is the most efficient power plant. This is because these power plants use more energy as an input and less waste heat for cooling as an output. Nuclear is the biggest water consumer in all the electricity generation technologies. Because of the lower steam temperature, more cooling water and steam is needed for nuclear power plants. This explains the vulnerability of nuclear power plants to constrained water availability (Faeth, 2012).

Fuel Type	Cooling	Technology	Median	Min	Max
Nuclear	Tower	Generic	1,101	800	2,600
	Once-through	Generic	44,350	25,000	60,000
	Pond	Generic	7,050	500	13,000
Natural Gas	Tower	Combined Cycle	253	150	283
		Steam	1,203	950	1,460
		Combined Cycle with CCS	496	487	506
	Once-through	Combined Cycle	11,380	7,500	20,000
		Steam	35,000	10,000	60,000
	Pond	Combined Cycle	5,950	5,950	5,950
	Dry	Combined Cycle	2	0	4
	Inlet	Steam	425	100	750
Coal	Tower	Generic	1,005	500	1,200
		Subcritical	531	463	678
		Supercritical	609	582	669
		IGCC	390	358	605
		Subcritical with CCS	1,277	1,224	1,329
		Supercritical with CCS	1,123	1,098	1,148
		IGCC with CCS	586	479	678
	Once-through	Generic	36,350	20,000	50,000
		Subcritical	27,088	27,046	27,113
		Supercritical	22,590	22,551	22,611
	Pond	Generic	12,225	300	24,000
		Subcritical	17,914	17,859	17,927
		Supercritical	15,046	14,996	15,057
Biopower	Tower	Steam	878	500	1,460
	Once-through	Steam	35,000	20,000	50,000
	Pond	Steam	450	300	600

Table 6. Water Withdrawal Factors for Electricity Generating Technologies (gal/MW) (From Macknick, Newmark, Heath, & Hallett, 2011).

Coal power plants are the second largest water consumers. They use water nearly as much as nuclear power plants. Pulverized coal uses more water than IGCC because it is slightly less efficient. Because it needs significantly less water than coal, natural gas is more efficient than coal. To compare the efficiency of both types of power plants, natural gas is 65–70% more efficient. But efficiency in a coal plant is about 35–40% (Faeth, 2012).

> The lower consumption values for cooling water are generally for cooling towers, though they also have higher values for consumption. When CCS technology is added to conventional fossil fuel generators, there is a considerable energy penalty encountered as carbon dioxide must be stripped from the flue gas, compressed, and disposed. For coal, this increases water needed for cooling by 90 percent, and for gas by 80 percent. These numbers assume that only the most efficient cooling options would be used with CCS" (Faeth, 2012).

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III. ELECTRICITY DEMAND, GENERATION AND AVAILABILITY OF WATER RESOURCES IN TURKEY

A. ELECTRICITY DEMAND IN TURKEY

Turkey's development in the industrial sector and in social welfare can compete internationally. This brings a rapid increase in energy consumption and this trend will likely continue in the following years. According to Turkey Ministry of Energy's 2010 data, as the largest share of energy supply, natural gas constituted 31.9% and coal and oil constituted, respectively, 30.7% and 26.7%. The remaining 10.7% was by renewable resources, especially hydro energy. Comparing 2010 to 2009, natural gas placed top in energy supply by replacing coal's position (ETKB, 2010). In terms of electricity and natural gas consumption growth rates in the last ten years, Turkey ranks first in Europe and second in the world after China (European Commission, 2011).

In Turkey, which had a population of 74 million in 2010, it is calculated that the per capita energy consumption increased by 1.3% (1482 kgoe) and electricity consumption increased by 8.56% (2347 kWh). This is shown in Table 7. As a net importer country, 72.9% of total 2010 energy supply was met by imports, of which oil made up 93%, natural gas 98% and hard coal 90% (ETKB, 2010). Some of the countries that Turkey imports natural gas from are Russia, Iran, Azerbaijan, and Algeria. Of the

total amount of imports, 56.6% is used in the production of electricity (BOTAS, 2010).

	2008	2009	2010	2009–2010 (variation)
Population	71,000,000	73,000,000	74,000,000	1.37%
Energy Consumption	1496 kgoe	1463 kgoe	1482 kgoe	1.30%
Electricity Consumption (Net)	2278 kWh	2162 kWh	2347 kWh	8.56%

Table 7. Per Capita Energy and Electricity Consumption by Years in Turkey (After EUAS, 2011).

There is a direct relationship between the level of development of a country and the share of final energy that is consumed by generating electricity. In 2011, compared with the previous year (210.4 TWh), electricity consumption increased by 8.98% and reached 229.3 TW. On the other hand, electricity generation in Turkey increased by 8.14% and reached 228.41 TWh compared with the previous year (211.21 TWh) (Turkish Electricity Transmission Corporation [TEIAS], 2011).

As of 2011, in terms of sources, 44.7% of the total electricity production was met by natural gas, 18.2% by domestic coal, 22.8% by hydro power, 10% by imported coal, 1.7% by liquid fuels, 2.1% by wind, and 0.5% by geothermal and biogas (TEIAS, 2011). According to the Electricity Energy Market and Supply Security Strategy Document published on May 18, 2009, Turkey is aiming to harness all hydraulic potential, domestic lignite and hard coal resources. It is also aiming to increase the installed capacity of wind power to 20,000 MW and the geothermal capacity to 600 MW for electricity generation until 2023 (ETKB, 2009). Turkey's goal is to reduce natural gas in electricity production to below 30% by 2023 and, by 2020, to supply 5% of the electricity production by nuclear energy.

After the privatization of electricity production, as of January 2012, construction of 543 new hydro power plants (capacities of 15,582 MW) has been going on in the private sector. As of 2004, the installed capacity of 18 MW by wind power has reached 3489 MW in 2011 after the implementation of the law on renewable resources. In order to meet the rapidly growing electricity demands and to reduce the risks from dependence on imports, new nuclear power plants that will constitute 20% of the total electricity production are planned to be built by 2023 (Yildiz, 2012).

In the TEIAS 2010–2019 Capacity Projection Report (2010), 2019 electricity demand is forecasted to reach 367348 GWh and 389980 GWh according to low and high demand scenarios, respectively. Table 8 demonstrates the electricity demand forecasted according to high and low demand scenarios (TEIAS, 2010).

YEAR	HIGH SCENARIO		LOW SCENARIO	
	ELECTRICTY DEMAND (GWh)	INCREASE (%)	ELECTRICTY DEMAND (GWh)	INCREASE (%)
2010	209000	7,7	209000	7,7
2011	219478	5,0	219478	5
2012	235939	7,5	234183	6,7
2013	253634	7,5	249873	6,7
2014	272657	7,5	266615	6,7
2015	293106	7,5	284478	6,7
2016	314796	7,4	303254	6,6
2017	338091	7,4	323268	6,6
2018	363110	7,4	344604	6,6
2019	389980	7,4	367348	6,6

Table 8. Electricity Demand Forecast between 2010–2019 (After TEIAS, 2010).

Turkey's General Directorate of Electricity Generation Company (EUAS), active in the field of electricity generation in the energy sector, implements operations, maintenance, and repair and rehabilitation activities of the state-owned thermal and hydroelectric power plants. EUAS, which has 80 hydroelectric plants with installed capacity of 11.639 MW and 19 thermal power plants with an installed capacity of 12.561 MW, met the 45.5% of the total installed capacity and 40.4% of Turkey's 2011 total generation of electricity.

In 2011, capacity utilization of EUAS's thermal power plants was 65.6% with an availability rate of 83.3%. In the same year, the hydraulic power plants' capacity utilization rate was 36.4% with an availability rate of 90.4% (EUAS, 2011). Table 9 demonstrates the capacity utilization rate and availability of the EUAS's thermal and hydro plants by year.

	Capacity Utilization Rate (%)			Availability (%)		
Years	2009	2010	2011	2009	2010	2011
Thermal Power Plants	74.1	68.6	65.6	87.4	85	83.3
Hydro Power Plants	28	40	36.4	90	92	90.4

Table 9. Capacity Utilization Rates and Availability of EUAS's Power Plants (After EUAS, 2011).

B. CURRENT ELECTRICITY GENERATION IN TURKEY

1. Overview

In the last two decades, the growth rate of the Turkish economy has been really high, it continues to increase. Although there are significant constraints in domestic energy resources, energy demand in Turkey is growing fast. The cause of this growth stems from the development of the industry sector which has an annual growth rate of 6–10% (Yarbay, Guler, and Yaman, 2011).

Turkey's energy consumption is low compared with countries in Western Europe. Turkey, however, has a huge growth potential in terms of population and industry. This is because Turkey has a large, young population. Also, the urban population has been increasing parallel with the industrial development (Investment Support and Promotion Agency of Turkey [ISPAT], 2010).

The growth rate Turkey's electricity market is one of the fastest in the world. The installed electricity generation capacity of Turkey has continued to increase regularly between 1998 and 2009—from 23354 MW to 44766 MW. The compound annual growth rate of this increase was 6.1% (ISPAT, 2010). The share of the producers in Turkey's installed capacity is shown in Figure 15 (EUAS, 2011).

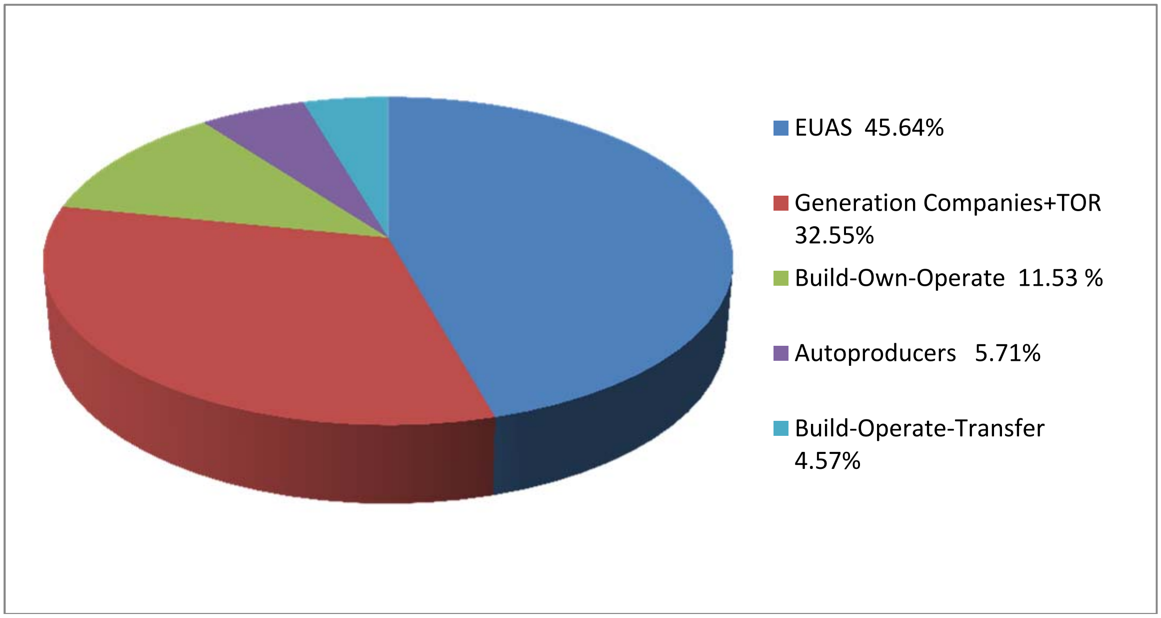

Figure 15. Share of the Producers in Turkey's Installed Capacity (After EUAS, 2011).

Turkey's electricity generation by primary resources is displayed in Figure 16. 2011.

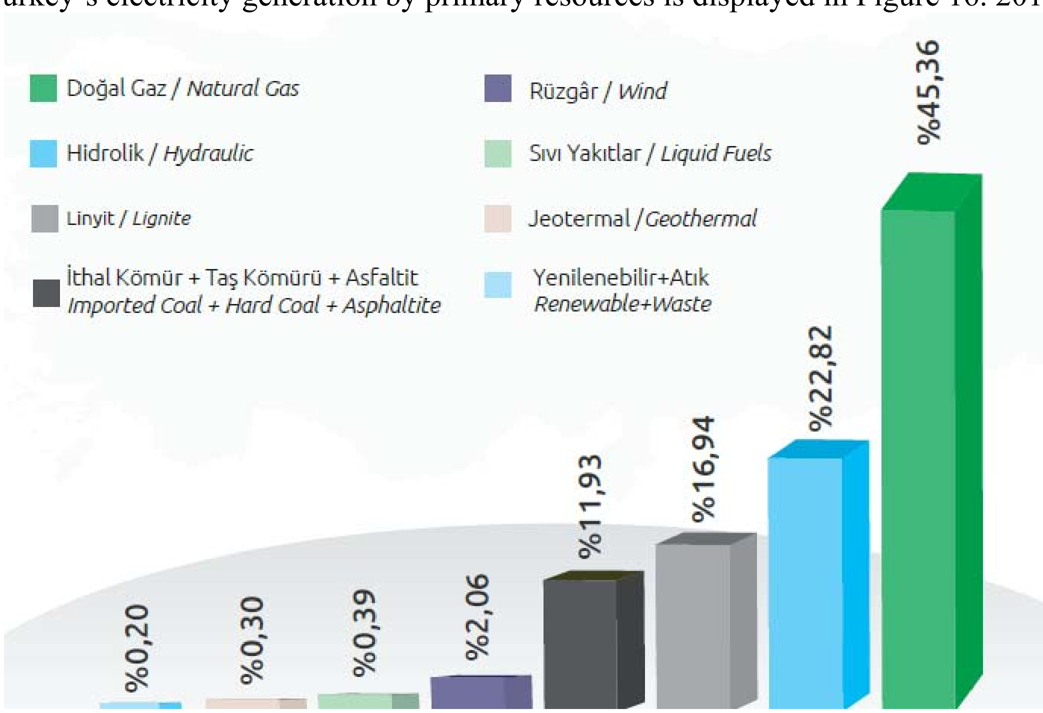

Figure 16. Turkey's Electricity Generation by Primary Resources (From EUAS, 2011).

Especially in the last decade, the Turkish energy industry has been going through a liberalization process with new regulations (ISPAT, 2010). This process started the adoption of new legislation. The aim of this liberalization process is to create a competitive electricity market. This competitive market will provide more reliable, sufficient, and good quality electricity generation to all consumers at a low cost (EUAS, 2011). This competition will also enable environmental care projects and electricity generation. Before it can be developed, this liberalization process needs more steps. The state-owned electricity distribution companies and power plants should be privatized. In addition to that, the private sector should build new power plants with the help of governmental incentives. Since 2004, Turkey has provided an efficient investment environment for all investors. With the help of this environment, many foreign investors have made investments in the Turkish electricity market. Foreign investors acquired state-owned and private companies and formed partnerships with local investors (ISPAT, 2010).

2. Electricity Generation with Nonrenewable Resources

Currently, Turkey is known as an energy importing country. Imported sources comprise more than half of the energy requirements. In total primary energy consumption, oil takes the biggest share. Turkey has large coal reserves, particularly of lignite (Yarbay, Guler, and Yaman, 2011).

Both the total installed capacity and the total electricity generation of Turkey are dominated by fossil fuels. As shown in Figure 17, the fossil fuels share in total electricity generation has been gradually increasing since 1990 (Ministry of Environment and Forestry [MoEF], 2010). Nonrenewable resources comprise the largest share of Turkey’s electricity supply that, in 2008, reached to the peak share of 82.5% (EIA, 2011).

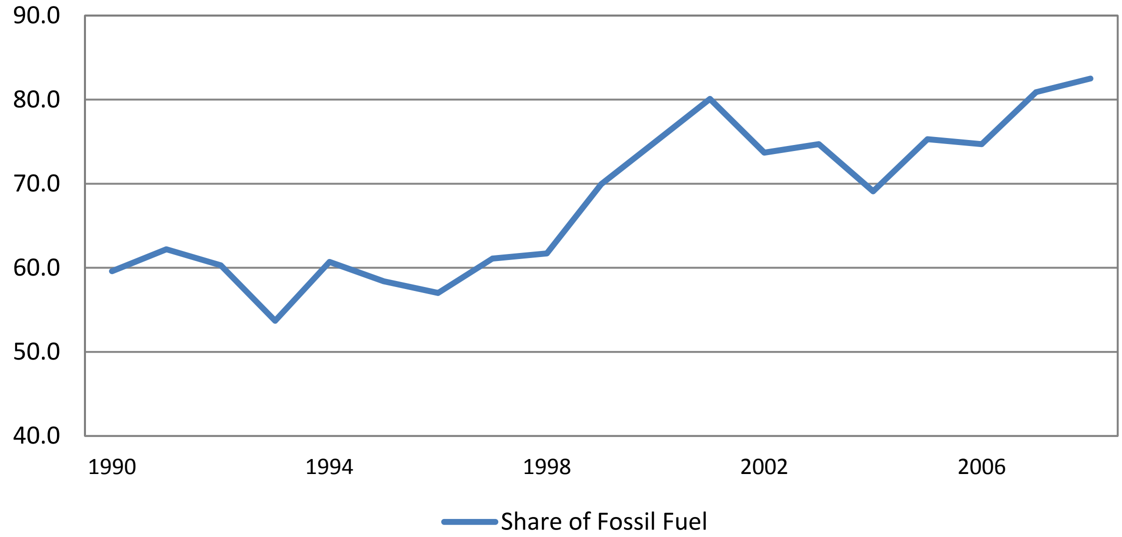

Figure 17. Share of Fossil Fuels in Electricity Generation of Turkey (From MoEF, 2010).

In 2010, fossil fuels comprised 65% of total installed capacity. Turkey's total installed capacity by sources is displayed in Figure 18 (MoEF, 2010).

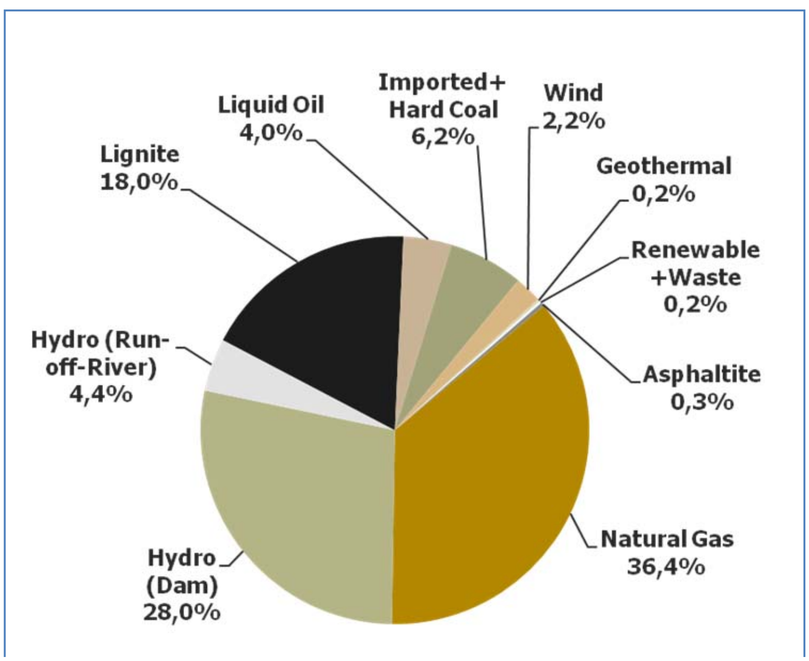

Figure 18. Total Installed Capacity by Sources in 2010 (From MoEF, 2010).

a. Coal

Turkey's most important domestic energy resource is lignite. The total lignite reserve is approximately 12 billion tons (EUAS, 2011). The biggest part of Turkey's lignite reserve is located in the Afsin-Elbistan basin of Southeastern Anatolia. This basin has approximately 40% of Turkey's total lignite reserve. Turkey's hard coal reserve is located in the Zonguldak basin of Northwestern Turkey (U.S. Energy Information Administration [EIA], 2011). In Turkey, the main purpose of coal is for power generation. Coal comprises approximately 30% of Turkey's total primary energy consumption (ISPAT, 2010). Turkey's coal production and consumption between 1999 and 2009 is shown in Figure 19.

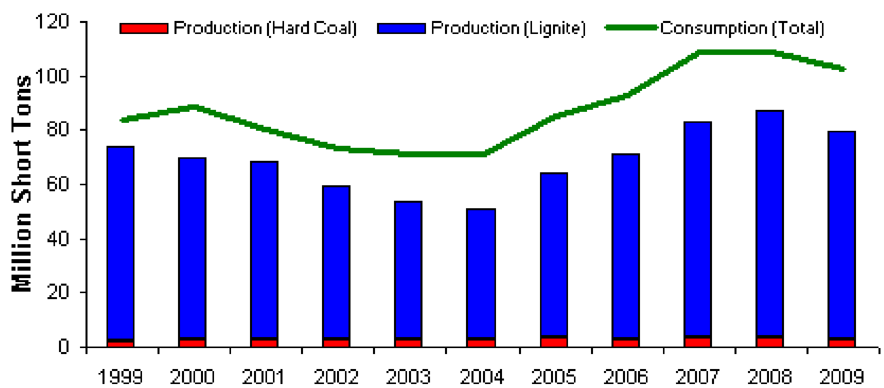

Figure 19. Turkey's Coal Production and Consumption (From EIA, 2011).

b. Natural Gas

Nonrenewable resources have historically been Turkey's largest power sources. Especially in the last decade, the share of natural gas-fired power plants has increased substantially (MoEF, 2010). Nearly half of the electricity generation is provided by natural gas-fired power plants. More natural gas-fired power plants are planned to be added to Turkey's conventional thermal generation power. As it is illustrated in Figure 20, natural gas had the biggest share with nearly half of total generation (49.7%). Lignite, imported coal, and hard coal also remain important energy sources with the share of 29.1%.

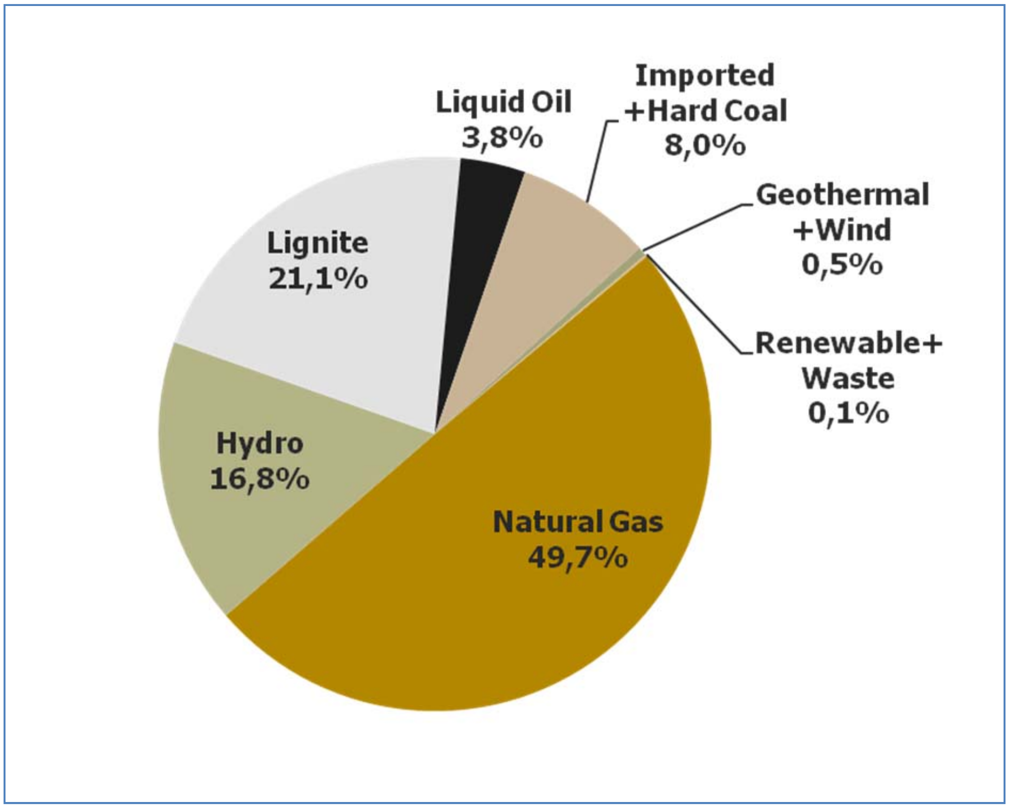

Figure 20. Electricity Generation and Shares by Sources in 2008 (From MoEF, 2010).

c. Nuclear

Turkey does not have a nuclear power plant. In 2011, the Ministry of Energy announced new goals about Turkey's nuclear power plant policy. First of all, the first nuclear power plant will be located in Akkuyu-Mersin. The construction will start in 2015 and electricity generation will start in 2020. This nuclear power plant will have four nuclear reactors. Each reactor will have a 1200 MW installed capacity. Most probably, the second nuclear power plant will be located in Sinop. There is no specific date for construction and electricity generation for this plant. This nuclear power plant will also have four nuclear reactors. Each reactor will have a 1550 MW installed capacity. Turkey wants to have at least 20 nuclear reactors by 2030. The main purpose of this target is to decrease the dependency on imported fossil fuels (EIA, 2011).

3. Electricity Generation with Renewable Resources

Turkey has the potential of significant renewable resources. Although there is considerable hydro, wind, solar, biomass and geothermal power potential, Turkey has only utilized its hydro potential by building hydroelectric power plants. In the last decade, with the new legislation in electricity market, the number of investments related to small-scale hydro, wind, and geothermal power plants has increased. The investments, however, are very insufficient when compared with the real potential of these resources. In addition, there are almost no investments in solar and biomass power (MoEF, 2010).

According to Strategic Plan published by the Ministry of Energy and Natural Resources for the period 2010–2014, the main target is to increase Turkey's renewable energy share to at least 30% in overall energy generation, including hydro power by 2023. Other goals in the strategic plan are: to increase the installed capacity for wind to 10,000 MW; to increase the installed capacity for geothermal power to 300 MW. In order to reach this target by 2023, all technical and economic potentials of renewable resources will be utilized.

The Energy Market Regulatory Authority (EMRA) is the main authority in the energy market in terms of renewable energy-related activities. The EMRA is accountable for issuing generation licenses. Since 2003, generation licenses for private sector have been issued by the EMRA. As shown in Figure 21, the total 2009 capacity of renewable energy issued to the private sector reached almost 20000 MW (MoEF, 2010).

Source	Capacity (MW)
Hydro	15.978,7
Wind	3.321,3
Geothermal	103,9
Biomass	57,2
Other	86,6
Total	**19.547,7**

Figure 21. Distribution of Renewable Generation Licenses by Source (From MoEF, 2010).

a. Hydro Power

Turkey has significant hydroelectric power resources. Hydro power has the second largest share in both total installed capacity and total electricity generation. By the end of 2011, the total installed hydro power comprised 32.39% of Turkey's total installed capacity and 22.82% of its total electricity generation. According to the Strategic Plan published by the Ministry of Energy and Natural Resources for the period 2010–2014, the main target is to add small hydroelectric power plants with a total installed capacity of 5000 MW. New hydropower plants will be built along the basin of the Tigris and Euphrates Rivers. Current plans include an additional 28 hydroelectric power plants in this region. The total generating capacity of these new hydroelectric power plants will be 6.2 GW (EIA, 2011). Assuming normal hydrological conditions, hydraulic potential of Turkey is about 130 TWh for one year (EUAS, 2011).

b. Wind Power

The wind energy potential of Turkey is calculated by the wind energy potential atlas (REPA). The domestic wind energy potential as of 2008 is shown in Table 10 (Ministry of Energy, 2010).

Type of Source	**Domestic Potential**
Wind	Very Efficient: 8.000 MW
	Moderately Efficient: 40.000 MW

Table 10. Domestic Wind Energy Potential as of 2008 (From Ministry of Energy, 2010).

Rapid progress has been made to increase the installed wind energy capacity in Turkey. In 2004, it was 18 MW, and, as of the end of 2009, it increased to 802.8 MW. With the new renewable energy law, licenses are accepted for new wind projects which will provide 3363 MW of total installed power (Ministry of Energy, 2010).

c. *Geothermal Energy*

Turkey is within in the first five countries in the world in terms of geothermal heating and spa practices. This includes China, the U.S., Japan, and Iceland. Turkey has high geothermal potential because of its location on the Alpine-Himalayan belt. Turkey's geothermal potential is about 31500 MW. So far, the Turkish Mineral Research and the Exploration Institute have made only 13% (4.000 MW) of this potential (Ministry of Energy, 2010). The current use of geothermal energy for electricity generation is 105 GW annually. The utilization rate of total geothermal potential of Turkey is only 3% (Yarbay, Guler, and Yaman, 2011). Turkey geothermal energy comprises approximately 0.3% of total installed capacity and total electricity generation (EUAS 2011).

d. *Solar Energy*

The Ministry of Energy defines Turkey's solar energy potential as "Having a high potential for solar energy due to its geographical position, Turkey's average annual total sunshine duration is calculated as 2.640 hours (daily total is 7,2 hours), and average total radiation pressure as 1.311 kWh/m^2-year (daily total is 3,6 kWh/m^2). Solar energy potential is calculated as 380 TWh/year" (Ministry of Energy, 2010). Installed solar cell capacity of Turkey has reached 1 MW. In Turkey, solar cells are used primarily for research purposes. These are mostly in public bodies and they supply only small amounts of power (Ministry of Energy, 2010).

C. WATER RESOURCES AVAILABILITY IN TURKEY

1. Water Potential of Turkey

In Turkey, the annual average rainfall is about 643 mm. This corresponds to 501 billion m^3 of water per year. Of this amount, 274 billion m^3 is water in the soil. The water returns to the atmosphere through evaporation and plant surfaces; some 69 billion m^3 feeds groundwater; and some 158 billion m^3 flows through rivers and discharges to the seas and the closed lake basins. In addition, an average of 7 billion m^3 of water comes from neighboring countries each year. Thus, the total annual surface water potential of Turkey is 193 billion m^3 (DSI, 2012).

Given the 41 billion m^3 of groundwater that feeds Turkey, it is calculated that Turkey has a total of 234 billion m^3 of renewable water potential. Under current technical and economic conditions, however, the potential surface water amount consumed for various intentions has an average total of only 98 billion m^3 per year. Turkey has a total of 112 billion m^3 consumable surface and underground water potential per year and, of this amount, 44 billion m^3 is currently used (DSI, 2012).

In terms of Turkey's water consumption by sector, the agriculture sector has the largest share with 74%; second is domestic water with 15%; and the industry sector is in third place at 11%.

Precipitation differs considerably both from year to year and among the river basins. The annual depth of precipitation is the highest in the Eastern Black Sea region and the lowest is in some parts of Central Anatolia. Most of the country's water potential lies in the southeast (28%) and the Black Sea Region (8%).

As it is demonstrated in Table 11, the Falkenmark indicator, which is the most widely used measure of water stress, categorizes the water conditions in an area as: no stress, stress, scarcity, and absolute scarcity The index thresholds of 1,700m^3 and 1000m^3 per capita per year are used as the thresholds between water stressed and scarce areas, respectively (Falkenmark, 1989).

Index (m^3 per capita)	**Category/Condition**
>1,700	No Stress
1,000-1,700	Stress
500-1,000	Scarcity
<500	Absolute Scarcity

Table 11. Water Barrier Differentiation (From Falkenmark, 1989).

In this context, Turkey is a country of water stress. It is not a water rich country in terms of water resources and water resources are not distributed equally over the country.

Turkey is situated in a semi-arid region. The amount of annual consumable water per capita is about 1519 m^3 in Turkey (DSI, 2012). Currently, the accessibility of water resources cannot meet the demands on time nor at the right location (European Environment Agency, 2010). There are some factors that prevent Turkey from controlling its water resources. Two factors are the topographical irregularities and the rivers that flow unsteadily. Also, the availability of water resources differs from region to region. For example, the Black Sea region has enough but unusable freshwater, while the Marmara and the Aegean regions, which are heavily populated and industrialized, lack sufficient freshwater (Turkish Ministry of Foreign Affairs, n.d.).

The United Nation's "Water Report (1994)" states that Turkey will be one of the countries most affected by climate change. This is because of its location in the Mediterranean Basin. Due to Turkey's climate conditions, the precipitation changes seasonally and from year to year. Natural water supply falls to minimum levels in the summer when the demand is at maximum. Turkey's water resources are very sensitive to drought conditions. Major droughts occur approximately every fifteen years. Therefore, the periodic droughts necessitate the construction of dams to regulate water and to meet the demand (DSI, 2010). In addition, the IPCC (Intergovernmental Panel on Climate Change) 4th Assessment Report states that the annual amount of precipitation and the number of precipitation days are very likely to decrease and the risk of summer droughts is likely to increase in most of the Mediterranean Region.

In Turkey, rivers are important for drinking water supply, irrigation, and for fishing. The Euphrates and the Tigris, which rise in Northeastern Anatolia and flow down through Turkey, Syria, and Iraq and join to form the Shatt-al-Arab 200 km before they flow into the Gulf, are two of the most famous rivers in the world. The combined water potential of these two rivers is almost equal to that of the Nile River (European Environment Agency, 2010). They account for about one third of Turkey's water potential (MFA, n.d.).

2. Water Resources Availability in the Future

According to the Turkey Statistical Institute (TSI) projections, the 2030 population of Turkey will be 100 million. In this case, the amount of water available per capita for the year 2030 will be about 1120 m^3 per year (DSI, 2009). Future projections of the DSI (2009) state that the share of water consumption by irrigation will decrease from 74% in 2008 to 64% by 2023. On the other hand, as is shown in Figure 22, the domestic and industrial consumption would increase to 16% and 20% respectively in this period. The current growth rate and the effect of factors, such as variation in water consumption patterns, may increase the consumption of water resources. For this reason, healthy and sufficient water resources for future generations in Turkey should be very well maintained and must be used rationally.

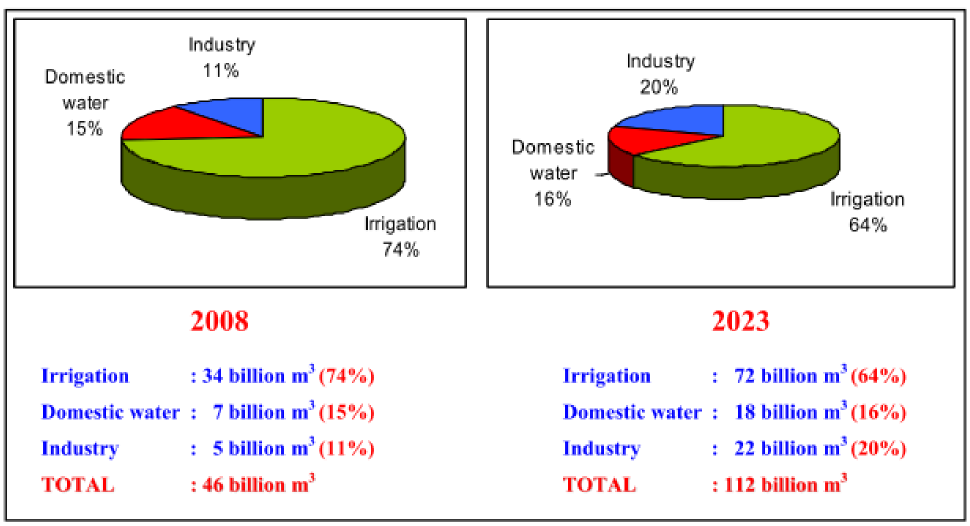

Figure 22. Actual Water Consumption and Projection for 2023 (DSI, 2009).

According to Keloglu (2006), in the future, domestic and industrial water consumption per capita will increase in Turkey, while the consumption of irrigation water per unit area will be reduced by using modern methods of irrigation. Considering Turkey's future of about 100 billion m^3 ground water and surface water potential, annual water supply per capita will reduce from 1370 m^3 in 2005 to 1000 m^3 in 2050. On the other hand, drinking and industrial water demand will increase from 7.6 billion m^3 in

2005 to 15 billion m^3 in 2050. It is estimated that total water demand will increase from 38.5 billion m^3 in 2005 to 61.9 billom m^3 in 2050 (Keloglu, 2006).

3. Water Management in Turkey

The General Directorate of State Hydrolic Works (DSI), founded in 1953 modeled after the Bureau of Reclamation in the U.S., is responsible for the planning, design, construction, and operation of nationwide hydraulic structures in Turkey. Today DSI is a subunit of the Ministry of Energy and Natural Resources.

The main approach of the General Directorate of State Hydraulic Works for the integrated water resources management is to manage them in a sustainable way in the basin scale. According to the DSI Water Report (2009), Turkey's water management policies are directed towards satisfying the increasing demands for domestic water, achieving food security, generation of energy, and conserving the environment in accordance with international standards.

In Turkey, water resources management is described in the five-year development plans specifying the general principles and priorities of the implementation of medium and long term economic, technical, environmental, social, and cultural policies. Turkey gives great importance to integrated regional development projects. Some of these projects are the Southeastern Anatolia Project (GAP), the Eastern Anatolia Project (DAP), and the Konya Plain Project (KOP) (DSI, 2009).

As the most significant project in Turkey, the Southeastern Anatolia Project (GAP), which is the largest investment for regional development in the history of the Turkish Republic, is a regional development project aimed at the socio-economic development of the Southeastern Region of Turkey, known historically as Upper Mesopotamia. This region has witnessed some of the earliest civilizations in the world. The project area covers nine provinces in Southeastern Turkey which corresponds to approximately 10% of Turkey's total population and an equivalent surface area. The water resources development program of the GAP includes thirteen groups of irrigation and energy projects, seven of which are on the Euphrates River and six on the Tigris. It is estimated that after the completion of the project, 1.8 million hectares of land, which corresponds to 21% of total irrigable land in Turkey, will be brought under irrigation. Electricity generation in the region will reach 27.387 GWh (20% of total electric energy potential in Turkey). Per capita income will rise by 209% and about 3.8 million people will have employment opportunities (DSI, 2009).

4. Water Conflict

Transboundary waters constitute 40% of Turkey's water potential (DSI, 2009). Coruh, Tigris, Euphrates, Kura and Aras, Meric, and Asi are the transboundary rivers of Turkey. These rivers have been a source of conflict throughout history.

In his article 'Water, War and Peace in Middle East" (Gleick P. , 1994), Gleick states that:

> As the 21st century approaches, population pressures, irrigation demands, and growing resource needs throughout the world are increasing the completion for freshwater. Nowhere is this more evident than in the arid Middle East, where the scarcity of water has played a central role in defining the political relationship of the region for thousands of year.

According to the DSI Water Report (2009), Turkey's transboundary water policy aims at the efficient utilization of transboundary water resources and the sharing of benefits through cooperation among riparian states. In the report it is stated that:

> Turkey believes that bilateral and riparian-only approaches are the most appropriate and result-oriented methods for resolving any disputes that arise during the utilization of transboundary water resources. Global approaches are not necessarily practical. Transboundary waters have their own specific characteristics and peculiarities. Each case of a transboundary water has its own social, economic, developmental, cultural and historic aspects. For this reason, the involvement of third parties cannot be fruitful for the settlement of any disputes. Transboundary waters have always emerged as an important theme during cooperation and peace settlement processes. This issue becomes much more critical when water is a scarce resource, as it is in the Middle East. Turkey has always stressed the principle of "good neighbourliness," which considers other riparians' interests when dealing with transboundary rivers. In this context, Turkey believes that sharing the benefits of water among riparian states is one way to ensure confidence building.

5. Turkey’s Dependence on Water for Energy

Turkey has considerable hydropower potential, among the highest in Europe. A large part of this potential will have to be developed by means of small hydropower plants (Bayazıt & Avcı, 1997). Turkey’s theoretical hydroelectric potential is 16% that of Europe. Turkey produces more than 45.000 GWh of hydroelectric power per year (which corresponds to 24.5% of its total power generation (EUAS, 2010). The gross theoretical viable hydroelectric potential in Turkey is 433 TWh and the technically viable potential is 216 TWh. The economically viable potential, however, is 140 TWh (DSI, 2010). In this context, when Turkey’s hydroelectric power potential is fully utilized, there will be no need for natural gas or coal-operated power stations.

In addition to hydropower plants that use water directly to generate electricity, thermal power plants also need considerable amount of water, especially for cooling. In 2010, the total amount of water that was withdrawn by thermal power plants was 4.29 billion m^3. Of this amount, 99% was used for cooling and 97% of this amount was withdrawn from seas. In the same year, 99% of wastewater was discharged to the sea again and a total of 17.33 million m^3 of wastewater discharged by thermal power plants were treated (TUIK, 2012).

IV. ANALYSIS

A. OPTIMIZATION MODEL

This chapter focuses on the project's building of an optimization model using the Microsoft Excel program to comprehend and evaluate the relationship between water resources and electricity generation in Turkey. Some of the data used in the model are excerpts from previous chapters. Also, there are a few assumptions about the data used in the model. Three different scenarios were used as assumptions in the model. These are high (worst), moderate, and low (optimist) consumption scenarios. Then, decision variables, objective functions, and constraints were defined to build the model. Only thermal power plants (nuclear, coal, natural gas) were considered for the model. We assigned annual projected electricity demand to the electricity constraint part.. For each scenario, both the proportion of thermal power plants in total electricity generation and the types of power plants cooling systems (once-through, tower, and pond) were changed. The optimization model was solved by using Microsoft Excel's solver function. Values were assigned to the electricity constraint value in order to obtain the minimum water withdrawal of Turkey for 2012, 2015, 2019, 2024, 2029, and 2034. The model for each years was solved to find the minimum water withdrawal value that is needed to generate the electricity demanded. Introducing the assumptions and scenarios, decision variables, objective function, and constraints will provide a better understanding of the model.

B. ASSUMPTIONS

The purpose of this optimization model is to comprehend the relationship between water resources and electricity generation. Because of that, other factors (raw material, technology, CO_2 emission, etc.) that affect electricity generation are neglected in the model.

As shown in Table 12, fossil fuels (natural gas, imported coal, and lignite) consist of almost 75% of Turkey's total electricity generation. Hence, natural gas and coal power plants were used in the model in terms of thermal power plants. Nuclear power plants were added to the model after 2020 to make the model more realistic. According to the

Ministry of Energy, nuclear power plants will start electricity generation in 2020. Until 2020, only natural gas and coal power plants were included in the model.

Primary Resources	
Natural Gas	45,36%
Hydroelectric	22,82%
Lignite + Imported Coal+Hard Coal +Asphaltit	16,94%
Imported Coal+Hard Coal +Asphaltit	11,93%
Wind	2,06%
Liquid Fuels	0,39%
Geothermal	0,30%
Renewable+Waste	0,20%

Table 12. Turkey's Electricity Generation by Primary Resources (From EUAS, 2011).

In the optimization model, the thermal power plants of EUAS (state electricity generation company), generation companies, transfer of operation rights(TOR), and build-own-operate were taken into consideration. As displayed in Table 13, these three producers share 90% of Turkey's total electricity generation. Build-operate-transfer and auto producers were excluded from the model because of their small share in overall electricity generation. Also, the thermal power plants have very small installed capacity.

Main Producers	
Euas (State Electricity Generation Company)	40,26%
Generation Companies + Transfer Of Operation Right (Tor)	29,21%
Build-Own-Operate	19,59%
Build-Operate-Transfer	5,06%
Otoproducers	5,34%

Table 13. Share of the Producers in Turkey's Installed Capacity (From EUAS, 2011).

The thermal plants in Turkey have diversity in terms of installed capacity. Some of them have big and some of them have small installed capacity. This project used the JMP program in order to mitigate the diversity. First of all, as is shown in Table 14, the natural gas power plants were sorted into four different types according to their installed capacity. Also, an assumption was made about their percentages in total natural gas power plants.

Natural Gas Power Plants	Installed Capacity (MW)	Percentage In Total Natural Plants
1	103	33
2	494	28
3	1273	25
4	8611	14

Table 14. Types of Natural Gas Power Plants and their Percentage in Total Natural Gas Plants.

Secondly, as is illustrated in Table 15, coal power plants were sorted into three different types regarding their installed capacity. Assumptions were made about their percentages in total coal power plants.

Coal Power Plants	Installed Capacity (MW)	Percentage In Total Coal Plants
1	1705	33
2	3019	33
3	7089	34

Table 15. Types of Coal Power Plants and their Percentage in Total Coal Plants.

In addition, even though Turkey does not have a nuclear power plant for now, as is displayed in Table 16, nuclear power plants the model sorted them into four different types regarding their capacity to consider them after 2020l. Assumptions were made about their percentages in total nuclear power plants.

Nuclear Power Plants	Installed Capacity(Mw)	Percentage In Total Nuclear Plants
1	1200	20
2	1400	30
3	1600	30
4	1800	20

Table 16. Types of Nuclear Power Plants and their Percentages in Total Nuclear Plants.

In the model, the productivity rate of all types of power plants is 70%. The annual electricity generation values are calculated according to this productivity rate.

In the model, as is illustrated in Table 17, we made assumptions about the type of power plants that will be used until 2034 and their percentage in total production. The percentages are projected for every five years period. For example, until 2020, there will be only natural gas and coal power plants in electricity generation. But, after 2020 we added nuclear power plants to the total electricity generation.

	2012	2015	2020	2025	2030
Nuclear	0%	0%	7%	13%	20%
Coal Fired	42%	42%	40%	40%	40%
Natural Gas	58%	58%	53%	47%	40%

Table 17. Future Projections of Each Type of Power Plant and Percentages in Total Production

High Consumption (Worst Case) Scenario

In this scenario, the assumption was made that thermal power plants consist of 74% of total electricity generation and all of the plants use once-through cooling systems. This cooling system needs more water than the others. The purpose of the high consumption scenario is to find the minimum amount of water withdrawal that will be needed for electricity generation demanded in the future with using the once-through cooling system.

Moderate Consumption (Average) Scenario

In this scenario, the assumption was made that thermal power plants consist of 66% of total electricity generation and all of the plants use pond cooling system. The purpose of the moderate consumption scenario is to find the minimum amount of water withdrawal that will be needed for electricity generation demanded in the future with using the pond cooling system..

Low Consumption (Optimist) Scenario

In this scenario, the assumption was made that thermal power plants consist of 54% of total electricity generation and all of the plants use tower cooling system. This cooling system needs less water than the others. The purpose of the low consumption scenario is to find the minimum amount of water withdrawal that will be needed for electricity generation demanded in the future with using the tower cooling system.

C. DECISION VARIABLES AND PARAMETERS

Xij: Number of i types thermal power plants that have j capacity level

i={1(nuclear), 2(coal), 3(natural gas),}

j={1(level1), 2(level2), 3(level3), 4(level4)} from low to high

Gij: The amount of reliable annual electricity generation for i type power plant that have j capacity level.

Wij: The amount of annual water needed for i type power plant that have j capacity level to generate electricity.

Gt: Total amount of annual electricity generation in the country.

Wseg: Total amount of water required for electricity generation.

P_{i-Y}: Percentage of i type power plant in total electricity generation amount for year y.

Y={2012,2015,2019,2024,2029,2034}.

P_{i-j}: Percentage of i type power plant that has capacity of level j in total i types power plants' electricity generation amount.

D. OBJECTIVE FUNCTION

$$Minimize \sum_{i=1}^{3}\sum_{j=1}^{4} \mathrm{Xij} * \mathrm{Wij}$$

The objective function of the model is to minimize the total withdrawal amount by using the given constraints. The total water withdrawal amount and the accumulation of water withdrawal amount that is used by all thermal power plants country wide is equal to multiplying each type of thermal power plants' annual water withdrawal amount with the number of each type of power plant. When calculating the water withdrawal amount for each type of power plant, we used Table 5 in Chapter II. In order to find the annual withdrawal amount for each type of plant, we multiplied the water withdrawal data that is necessary to generate 1 MWh with the annual electricity generation of each type of plant. Water withdrawal will show diversity regarding the cooling system we used in each scenario. The objective function for high consumption scenario is:

Min $326327X_{11+}$ $380700X_{12+}$ $435117X_{13+}$ $489491X_{14+}$ $48892\ X_{21+}$ $86572X_{22+}$ $203284X_{23+}$ $1172\ X_{31+}$ $5621X_{32+}$ $14486X_{33+}$ $97993X_{34\,=}$ Wseg

for moderate consumption scenario:

Min $51874\ X_{11+}$ $60517X_{12+}$ $69168X_{13+}$ $77811X_{14}$ + $25680X_{21+}$ $45471X_{22+}$ $106772X_{23+}$ $612X_{31+}$ $2939X_{32+}$ $7574X_{33+}$ $51235X_{34}$ = Wseg

for low consumption scenario:

Min $8101X_{11+}$ $9450X_{12+}$ $10801\ X_{13+}$ $12152\ X_{14+}$ $1345\ X_{21}$ + $2381\ X_{22+}$ $5591\ X_{23}$ +$26X_{31}$ + $125X_{32+}$ $322\ X_{33+}$ $2178\ X_{34}$ = Wseg

E. CONSTRAINTS

The model used two constraints: projected electricity demand and policy constraints that are determined by government. It is evident that there are many factors that affect water withdrawal amount, such as cost of investment, type of primary resource, and CO_2 emission regulations. Only used two types of constraints, however were used in order to demonstrate the effect of electricity demand and policy constraints.

Besides, if other factors were used as constraints, these would have limited the objective function before the electricity demand constraint. In this case, the direct relationship between water and electricity generation could not be demonstrated.

1. Electricity Demand Constraint

$$\sum_{i=1}^{3}\sum_{j=1}^{4} \mathrm{Xij} * \mathrm{Gij} \geq Gt$$

When calculating the electricity demand for each type of power plant, we used TEIAS data related with the annual reliable electricity generation of each thermal power plants in Turkey by using JMP program. According to the results of the JMP program, we categorized the nuclear and natural gas power plants into four and coal fired power plants into three based on their production capacity The electricity demand constraint for all scenarios:

$7358X_{11+}$ $8584X_{12+}$ $9811X_{13+}$ $11037X_{14+}$ $1705X_{21+}$ $3019X_{22+}$ $7089X_{23+}$ $103X_{31+}$ $494X_{32+}$ $1273X_{33+}$ $8611X_{34} \leq$ Gt.

2. Policy Constraint

The policy constraint is about the proportion of each type of power plant (nuclear, natural gas, and coal) in total electricity generation. When determining this policy, the government considers the availability of primary resources, environmental issues, and some international rules in the future (such as the Kyoto Protocol). In the model, the share of each type of power plant in total electricity generation was changed for each five year period and, then, the model was run each time for the specific year. The nuclear and natural gas power plants were sorted into four categories; the coal-fired power plants were sorted into three different categories regarding their installed capacity. As was previously defined, Table 16 was created based on policy constraints' assumptions. In the model, the policy constraint values were assigned from this table from the right hand side of the equation.

The policy constraint for nuclear power plants is:

$$\sum_{j=1}^{4} G_{1j} * X_{1j} \leq P_{1-y} * \sum_{i=1}^{3} \sum_{j=1}^{4} G_{ij} * X_{ij}$$

For coal fired power plants:

$$\sum_{j=1}^{3} G_{2j} * X_{2j} \leq P_{2-y} * \sum_{i=1}^{3} \sum_{j=1}^{4} G_{ij} * X_{ij}$$

For natural gas power plants:

$$\sum_{j=1}^{4} G_{3j} * X_{3j} \leq P_{3-y} * \sum_{i=1}^{3} \sum_{j=1}^{4} G_{ij} * X_{ij}$$

Additionally, each power plant was categorized into four different capacity levels and assigned different rates as shown in Table 18. For instance, nuclear power plants that have level 1 capacity constitute 20% of the total nuclear power plants' electricity generation amount.

Types	Level1	Level2	Level3	Level4	Total
Nuclear	20%	30%	30%	20%	100%
Coal Fired	33%	33%	34%		100%
Natural Gas	33%	28%	25%	14%	100%

Table 18. Percentage of Each Level of Power Plants in Total Electricity Generation.

Formulas for second policy constraint are:

$$G_{1j} * X_{1j} = P_{1-j} * \sum_{j=1}^{4} G_{1j} * X_{1j}$$

$$G_{2j} * X_{2j} = P_{2-j} * \sum_{j=1}^{3} G_{2j} * X_{2j}$$

$$G_{3j} * X_{3j} = P_{3-j} * \sum_{j=1}^{4} G_{3j} * X_{3j}$$

F. RESULTS AND DISCUSSION

1. High Consumption (Worst Case) Scenario

In this scenario, the assumption was made that thermal power plants consist of 74% of total electricity generation and all of the plants use once-through cooling systems. The purpose of the high consumption scenario is to find the minimum amount of water withdrawal that will be utilized to generate the electricity that is needed to meet the demand in the future with using most water consumptive system. The future electricity demand projections were obtained from the government company's annual report. These projections were made for 2012, 2015, 2019, 2024, 2029, and 2034. To find the minimum water withdrawal amount for specific years, electricity demand projections were assigned to right-hand side of the electricity constraints in the model. Then the model for 2012, 2015, 2019, 2024, 2029, and 2034 was solved. Finally, different water withdrawal amounts for these years were obtained, as shown in Table 19.

Years	Electricity Demand (GW)	Water Withdrawal (billion gallons)
2012	180138	3350
2015	224324	4182
2019	299078	5575
2024	427207	8802
2029	610464	13786
2034	872331	21713

Table 19. Water Withdrawal and Electricity Generation for High Consumption Scenario.

Using this data, Figure 23 was created to show the water withdrawal amount (billion gallons) and the annual electricity generation (GW) by years.

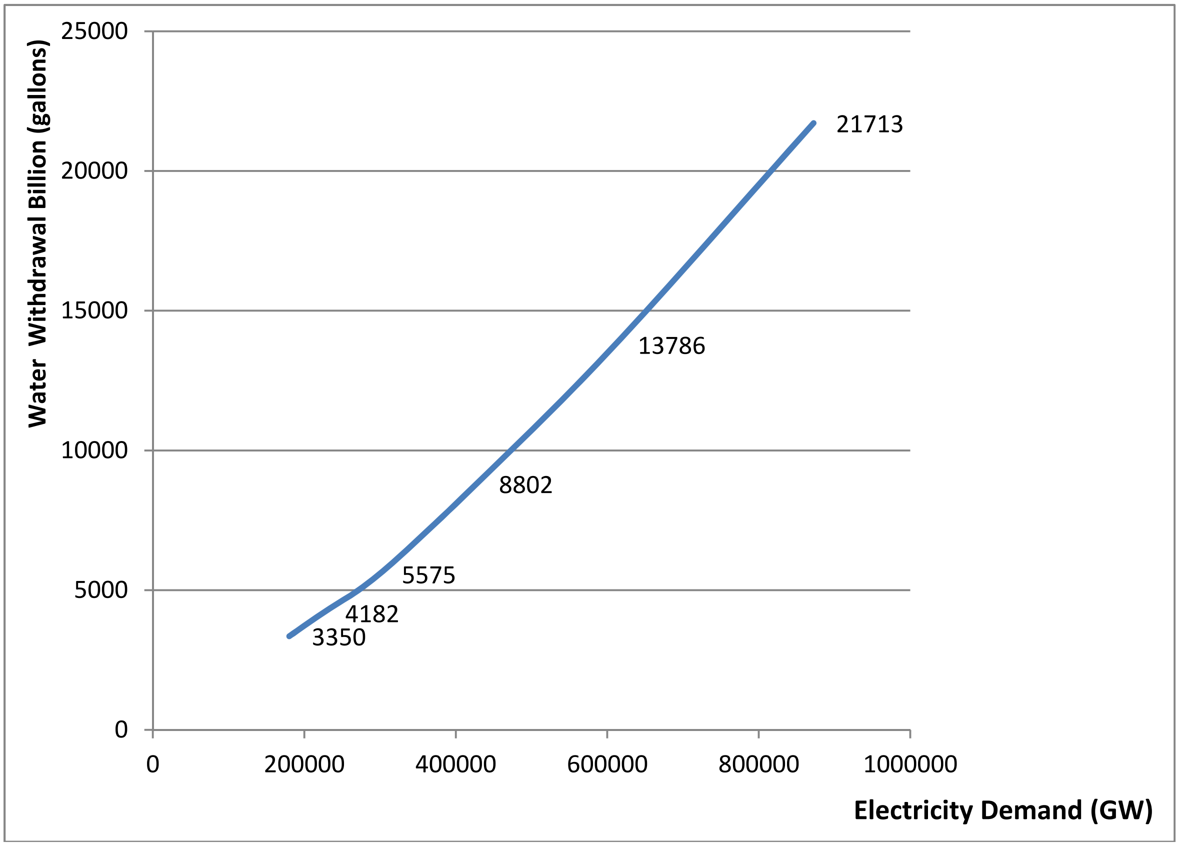

Figure 23. Water Withdrawal and Electricity Generation Graph for High Consumption Scenario.

When looking at Figure 23, it is obvious that there is a linear relation between the water withdrawal amount and the electricity generation. When the electricity demand increased, the water withdrawal amount also increased. The line that is shown in Figure 23 can be assessed as an efficient frontier. Ignoring other factors that affect the water withdrawal, this shows the minimum water withdrawal amount by using the electricity demand constraint. According to Figure 23, the water withdrawal amount in the high consumption scenario poses a substantial threat to electricity generation in the future. Figure 24 shows the water consumption projection for 2023. The conversion of the 2024 water withdrawal amount, which is 8,802 billion gallons, equals 33 billion m^3. This number obtained from the model was far above the projections made by government institutions. According to projections for 2023, 33 billion m^3 will be 33% of Turkey's total withdrawal. Comparing this water withdrawal amount for electricity generation in 2024, it is above the total industry water consumption projection which is 22 billion m^3. Even though the water resources allocated for total industry is used for electricity generation, it will still be insufficient to meet the demand for 2024. Even though half of the water withdrawal (16.5 billion m^3) is provided by sea water, the other half that is needed for electricity generation comprises 75% of the water that is allocated for the total industry.

Especially after 2020, according to this model's estimations, even though half of the water withdrawal amount is obtained by sea water, Turkey's electricity generation will be under a big threat in terms of water resources. If the effects of global warming and Turkey's fast growing population are included, the allocated water for electricity generation might be less than this model projects. So, the threat for electricity generation will be worse. Turkey will not able to generate enough electricity to meet its future demand. Hence, Turkey will have to be more efficient while using its electricity and/or utilize more sea water for electricity generation. Otherwise, Turkey may have to import the electricity to meet the demand.

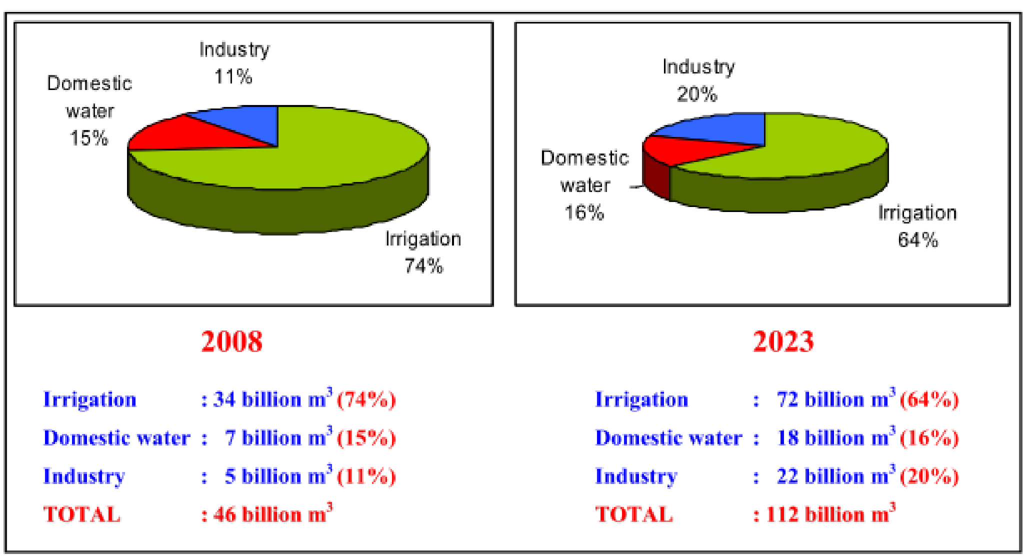

Figure 24. Actual Water Consumption and Projection for 2023 (DSI, 2009).

2. Moderate Consumption Scenario

In this scenario, the assumption was made that thermal power plants consist of 66% of total electricity generation and all of the plants use a pond cooling system. The purpose of the moderate consumption scenario is to find the minimum amount of water withdrawal that will be utilized to generate the electricity that is needed to meet the demand in the future with using moderate consumptive cooling system. The same processes were applied to the model as for the high consumption scenario. The result is Table 20.

Year	Electricity Demand (GW)	Water withdrawal (billion gallons)
2012	160664	1570
2015	200072	1955
2019	266746	2607
2024	381023	3684
2029	544468	5301
2034	778025	7635

Table 20. Water Withdrawal and Electricity Generation for Moderate Consumption Scenario.

Using this data, Figure 25 was created to show the water withdrawal amount (billion gallons) and the annual electricity generation (GW) by years.

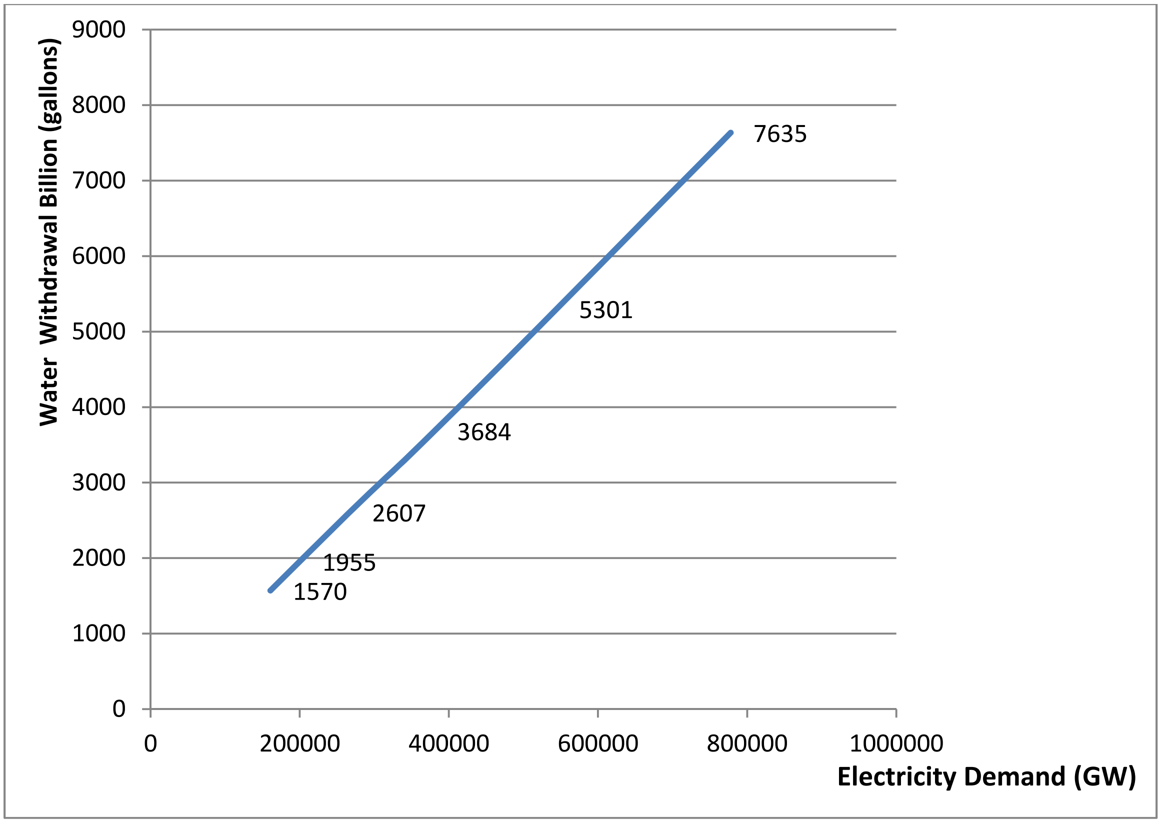

Figure 25. Water Withdrawal and Electricity Generation for Moderate Consumption Scenario.

According to the Figure 25, the water withdrawal amount in the moderate consumption scenario does not pose a substantial threat to electricity generation in the future. Figure 24 shows the water consumption projection for 2023. The conversion of the 2024 water withdrawal amount, which is 3,684 billion gallons, equals approximately 14 billion m^3. This number was obtained from the model and comprises 12.5% of Turkey's total withdrawal according to the 2023 projections. Comparing the water withdrawal amount for electricity generation of 2024 is 63% of the total industry water consumption projection which is 22 billion m^3. When the water resources allocated for the total industry is used for electricity generation, it will be sufficient to meet the demand for 2024. The 63%, however, consists of a very high proportion of total industry water resources. If the half of the water withdrawal (7 billion m^3) is provided by sea water, the other half that is needed for electricity generation comprises the 32% of the water that is allocated for the total industry. According to this models estimations for each year, there will be minor threats to future generations about the availability of electricity generation in Turkey. Thus, Turkey should be more efficient in using its electricity. Also, more sea water should be used for electricity generation. These precautions may just mitigate the threat for the future.

3. Low Consumption (Optimist Case) Scenario

In this scenario, the assumption was made that thermal power plants consist of 54% of total electricity generation and the entire plants use tower cooling systems. The purpose of the low consumption scenario is to find the minimum amount of water withdrawal that will be utilized to generate the electricity that is needed to meet the demand in the future with using the least consumptive cooling system. The same processes were applied to the model as for the high and moderate consumption scenarios. Table 21 was the result.

Years	Electricity Demand (GW)	Water withdrawal (billion gallons)
2012	131452	62
2015	163696	78
2019	218246	104
2024	311746	164
2029	445474	257
2034	636566	405

Table 21. Water Withdrawal and Electricity Generation for Low Consumption Scenario.

Using data from Table 21, Figure 26 was created to show the water withdrawal amount (billion gallons) and the annual electricity generation (GW) by years.

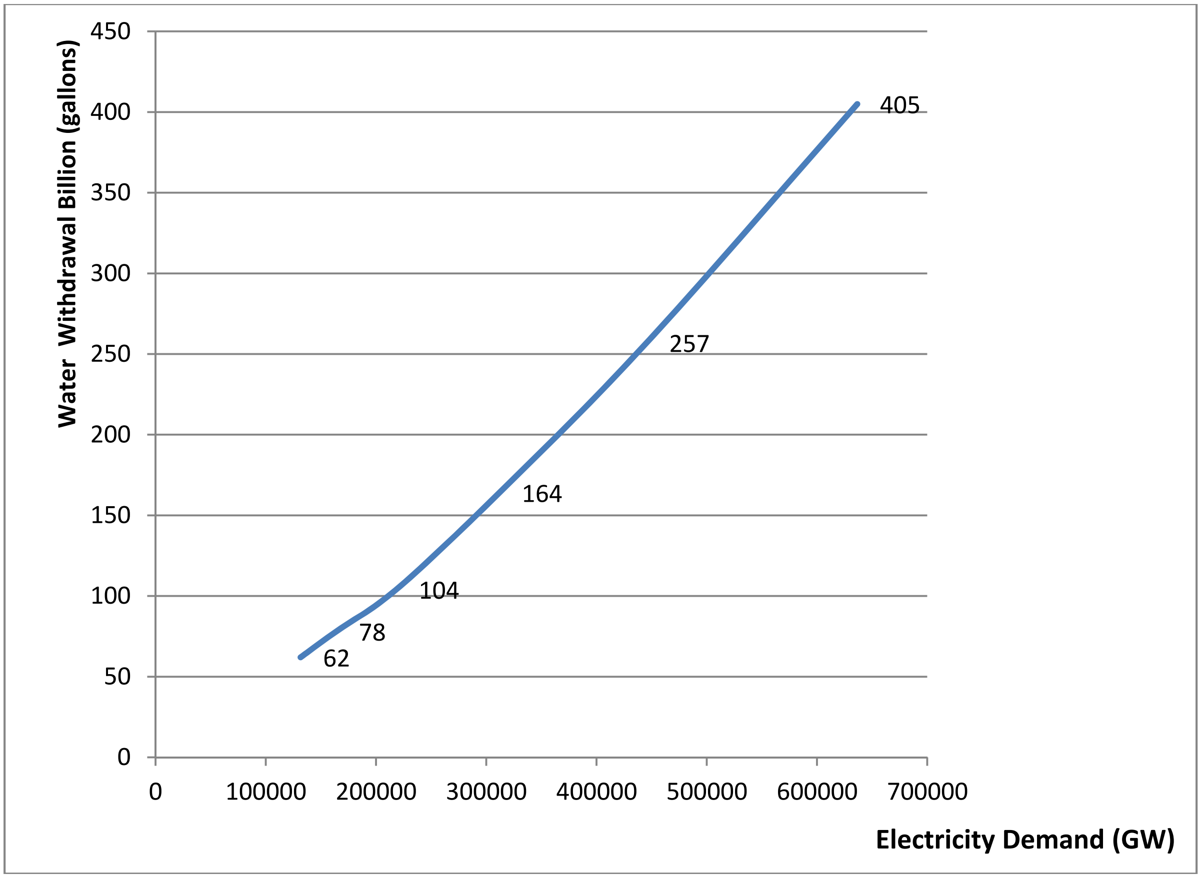

Figure 26. Water Withdrawal and Electricity Generation for Low Consumption Scenario.

According to Figure 26, the water withdrawal amount in the low consumption scenario does not pose a threat to electricity generation in the future. Figure 24 shows the water consumption projection for 2023. Even the conversion of 2034 the water withdrawal amount, which is 405 billion gallons, equals approximately 1.53 billion m^3. This number was obtained from the model and comprises 1% of Turkey's total withdrawal according to projections for 2023. Therefore, 1.53 billion m^3 is far below the projections. In addition, this number is better than Turkey's current water withdrawal amount. Comparing the 2034 water withdrawal amount for electricity generation, this is 6% of the total industry water consumption projection which is 22 billion m^3. This is the best case scenario for Turkey. This means that there is no threat for the future electricity generation in terms of water withdrawal.

Figure 27 combines the three different consumption scenarios on a single graph. When looking at the combined graph, the big diversities amongst the scenarios can easily be distinguished. The water withdrawal and electricity generation values show big differences. This is especially true for the water withdrawal values which show huge differences. The differences of electricity generation depend on the share of the thermal power plants in total electricity generation. This huge water withdrawal difference stems from the cooling system of thermal power plants. The water withdrawal amount shows great variety based on their cooling systems. The selection of cooling system types is vital in terms of water withdrawal. It can be inferred that the selection of a cooling system should be the top priority in regards to thermal power plants in order to mitigate water consumption. Otherwise, their water withdrawal will significantly affect the water resources that will be used for the future.

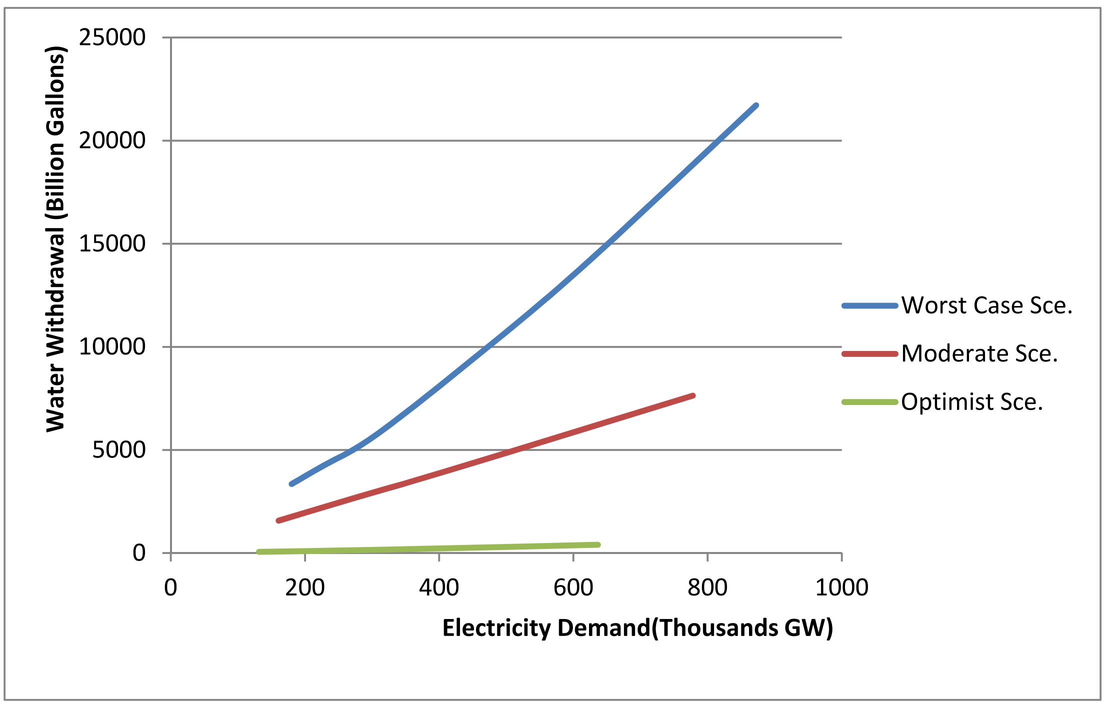

Figure 27. Combined Water Withdrawal and Electricity Generation Graph for Three Scenarios.

V. CONCLUSIONS

A. SUMMARY

As described in Chapter II, energy and water are interdependent and critical resources. The availability of water resources has a substantial impact on electricity generation. While electricity demand is increasing in proportion to national growth and economic development, water supply limitation is growing in many countries.

Although the current water supply is not regarded as a constraint on Turkey's current annual electricity generation capacity, it is obvious that it will have an impact on electricity generation in the future. This is especially true in the case of a likely emerging local or country wide drought. In Turkey, parallel with the national growth, industrial development and increasing population, demand for electricity will continue to grow in the following years. According to TEIAS's projections, Turkey's annual electricity demand will increase from 243,400 GWh in 2012 to 433900 GWh in 2020 with an average of 7.4% yearly growth rate. On the other hand, if the potential freshwater resources are not used efficiently in Turkey, seasonal water resources reductions in some regions are likely. Furthermore, climate variability and changes may adversely affect the surface water reservoir storage by affecting the amount of snow fall and precipitation. The Central Anatolia and Southeast Anatolia regions are especially susceptible to climate variability and drought. Reduction in water resources may lead to some imbalances in the distribution of water to sectors. In other words, if the amount of water allocated for irrigation is maintained at the same rate in the future, the time the amount of water that is allocated for electricity generation will decrease or stay the same. In this case, since low water levels from drought and competing uses may limit the ability of power plants to generate power, difficulties in meeting the total electricity demand can be seen.

A substantial portion of the water that is needed in electricity generation is used for cooling purposes. Thus, power plants that harness nonrenewable energy in electricity generation use more water than the others that harness renewable energy sources, such as wind and solar. Thermal power plants are the most in need of water among the power plants. Lack of adequate water for thermal power plant cooling may contribute to power shortages. This is especially important for many of the water-stressed regions, especially in the summer. For example, in 2003, the French government shutdown 4,000 megawatts of nuclear generation capacity because of high temperatures and low river levels (The Guardian 2003).

Water requirements for thermoelectric power plants are mainly dependent on three factors: the type of cooling system employed at the plant, the efficiency of the plant in converting thermal energy to electrical energy, and the fuel type used in the plant (Cooley, Fulton and Gleick, 2011). Wet cooling technologies, such as once-through systems and recirculation systems, are more vulnerable to water shortages.

In this study, how much total water withdrawal for electricity generation will change depending on the technology and cooling system that used in thermal power plant was analyzed. As it was mentioned in Chapter IV, when the results of the high consumption scenario are examined, to meet the 2024 electricity demand, 33 billion m^3 of water withdrawal is needed. This amount, however, is far above the projected water amount that is allocated for electricity generation for this specific year. In the low consumption scenario, however, the 2034 water withdrawal value obtained from the model is 1.53 billion m^3. Turkey can meet this demand easily with its own water resources. In addition, as is seen in the model, the water withdrawal that is allocated for electricity generation is affected by the diversity in the energy policy. The differences and shares of renewable and nonrenewable resources used in electricity generation will affect water withdrawal significantly.

The thermal power plants use different primary resources to generate electricity. Table 6 shows the differences in their different primary resource usage, their water withdrawal, and their diversity. Hence, their share in total electricity generation in the country will change the water withdrawal amount that is needed to meet Turkey's electricity demand.

Additionally, an assumption was made for the model: an average 7.4% increase in annual electricity demand based on the TEIAS projection. This demand, however, may be lower than projected if the government takes specific measures to save electricity consumption. Thus, electricity savings will directly affect water withdrawal for electricity generation and water withdrawal amount will be lower than the expected amount.

B. RECOMMENDATIONS

As described in Chapter II, the water withdrawal factor per unit of electricity generated is dependent mainly on the choice of technologies and cooling systems employed. Also, as is shown in the optimization model results, cooling systems of the thermal power plants have a profound impact on water withdrawal amount. Thus, electricity generation companies should look for a way to use dry cooling systems in power plants even though they have a higher capital cost.

As shown in Table 4, since renewable technologies need minimal amounts of water per unit of electricity generation, Turkey’s government should motivate companies to increase the portion of power plants that use nonrenewable sources in their electricity generation portfolios.

According to the results of this model in the high consumption scenario (assuming all thermal power plants use once-through cooling system), it is obvious that the water withdrawal amount for electricity generation is too high to be met by potential water resources. Thus, Turkey should take measures to prevent electricity generation companies from using water resources inefficiently and it should limit the usage of inefficient technologies and cooling system configurations. This will help to reduce pressure on the already limited water resources. On the other hand, in the low consumption scenario, assuming that all thermal power plants use tower recirculation cooling systems, the water withdrawal amount for electricity generation will be low.

Furthermore, the amount of water needed for electricity generation can be reduced by utilizing dry cooling systems. Using this technology may prevent the adverse effect of drought and climate change. Thus, both scientists and companies should deeply work on this issue to find new technologies that are less water intensive. The Turkish government and the companies’ board of directors should encourage these researches.

Instead of freshwater resources, water withdrawal amounts for electricity generation can be met by non-fresh water resources, such as municipal water. This may decrease the amount of freshwater that is needed in electricity generation. Besides, in coastal areas, saline water can be used for cooling instead of freshwater.

As mentioned in Chapter II in the 'Water and Energy Nexus' section, while the cooling system has a high water withdrawal factor and a low water consumption factor, tower technology has a low water withdrawal and a high water consumption factor. Thus, this should be taken into consideration when deciding regional cooling system policies and regulations.

As is shown in the analysis of the high consumption scenario, as an old technology, once-through cooling systems have a high water withdrawal factor. Thus, the government and the companies should find a way to retire existing power plants that use old technologies.

Not only are the thermal power plants vulnerable to the lack of water stemming from drought or climate change, but also the hydroelectric power is drought-sensitive. So, relying solely on hydropower to meet future electricity demands may not be the best course of action.

With the new regulations of Turkish government, electricity generation companies should improve their use of solar photovoltaic, wind, and air-cooled geothermal hot water (binary) power systems because they consume almost no water while producing electricity. Of course, these types of systems have some limitations, such as cost issues and finding a proper location to build.

Based on the analysis of this model, since water supply and electricity demand affect each other, the Turkish government should integrate the energy and water policies to develop collaborative plans for the future. It requires an analysis of the water and efficiency implications of various types of cooling options and the technologies applicable to the new power plants. Besides, Turkey's government should create a mechanism to coordinate action between the water and energy policies by considering the security of these resources.

In order to make a more accurate analysis, data related from each power plant's cooling system, technology, and water withdrawal factors for electricity generation should be gathered. This data should be provided by both the Ministry of Energy and by private electricity generation companies.

C. FUTURE RESEARCH

Existing data related to the water withdrawal factor of power plants is currently not adequate. Collecting accurate and up-to-data related to the water withdrawal factor of power plants will provide a better evaluation of water impact on electricity generation. It requires getting every individual power plant's data and to organize this on a regional level. In this way, the number of assumptions can be reduced and different models can be developed by taking into consideration the regional characteristics. Also, several studies should be done in order to evaluate the effects of new cooling systems and technologies on the water withdrawal factor.

This study's optimization model did not evaluate the effects of the water withdrawal amount of hydropower plants for electricity generation. In future studies, after gathering data related to the water amount that is needed for hydropower plants to generate electricity, how much water is required in the reservoirs to meet future electricity demand should be calculated.

Finally, in addition to water and policy constraints, some factors, such as the availability of primary resources, the cost of investment and CO_2 emission can be included to facilitate comprehensive models to find the maximum amount of electricity generation required.

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